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A Manual of

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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms, in making these volumes thoroughly representative of the best and latest practice in the design and construction of steam and electrical machines and machine tools; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

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THE Cyclopedia of Engineering is compiled from the most practical and comprehensive instruction papers of the American School of Correspondence. It is intended to furnish instruction to those who cannot take a correspondence course, in the same manner as the American School of Correspondence affords instruction to those who cannot attend a resident engineering college.

¶ The instruction papers forming the Cyclopedia have been prepared especially for home study by acknowledged authorities, and represent the most careful study of actual shop needs and conditions. Although primarily intended for correspondence study, they are in use as text books by Columbia University, Lehigh University, Iowa State College, the University of Maine, the U. S. Government in its School of Submarine Defense, the Westinghouse Companies in their Shop School, and for reference in the leading colleges, shops and public libraries.

¶ Years of experience in the shop, laboratory, and class-room have been required in the preparation of the various sections of the Cyclopedia. Each section has been tested by actual use for its practical value to the man who desires to know the latest and best practice in the shop or engine room.

¶ Numerous examples for practice are inserted at intervals; these, with the test questions, help the reader to fix in mind the essential points, thus combining the advantages of a text book with a reference work.

¶ Grateful acknowledgment is due to the corps of writers and collaborators, who have prepared the many sections of this work. The hearty co-operation of these men—engineers of wide practical experience and acknowledged ability — has alone made these volumes possible.

¶ The Cyclopedia has been compiled with the idea of making it a work thoroughly technical yet easily comprehended by the man who has but little time in which to acquaint himself with the fundamental branches of practical engineering. If, therefore, it should benefit any of the large number of workers who need, yet lack, technical training, the editors will feel that its mission has been accomplished.

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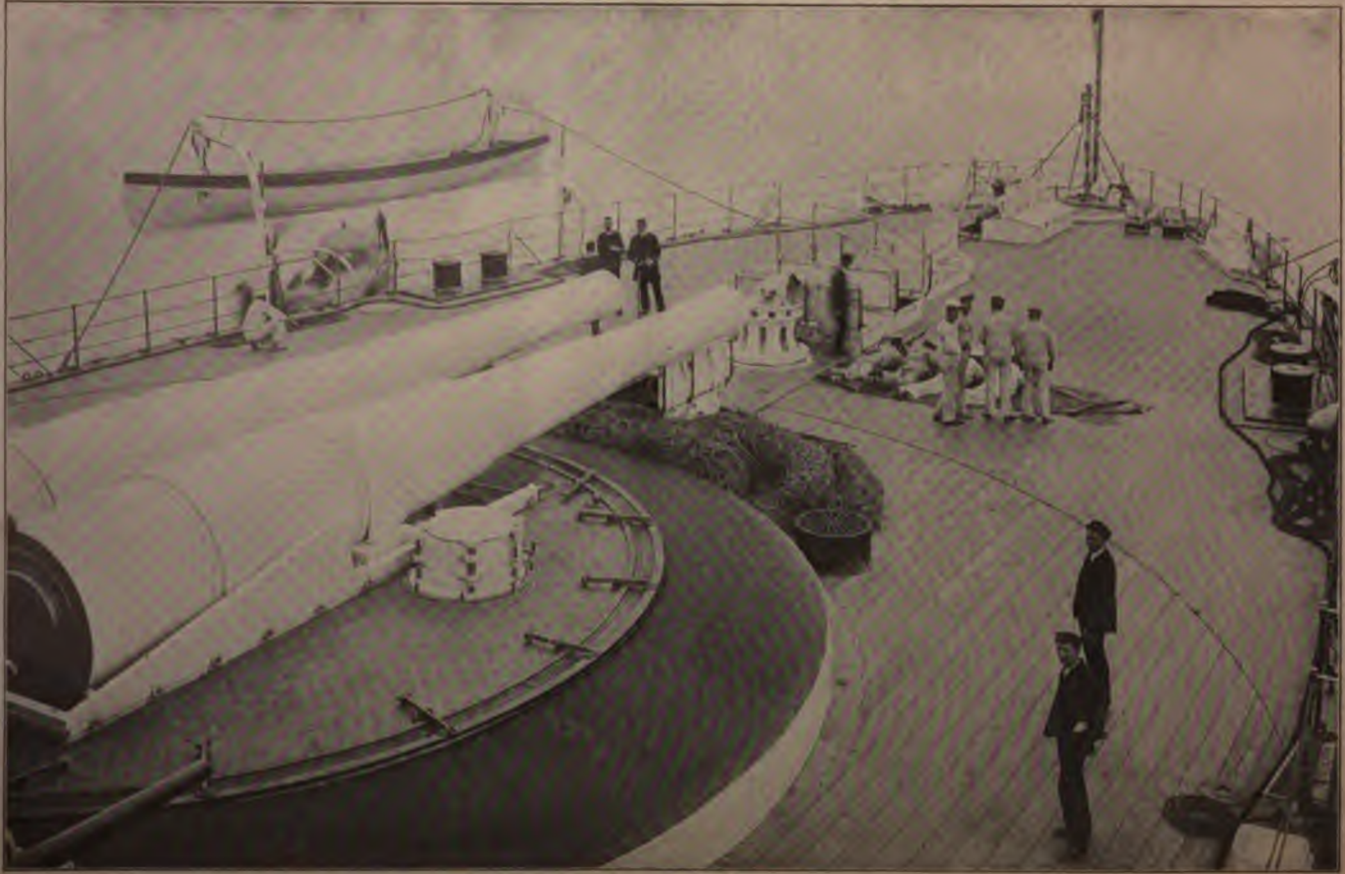

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MARINE BOILERS.

The marine boilers now used may be divided into three distinct classes which in turn may be subdivided. These general classes are,

1. The rectangular or box boiler.
2. The cylindrical, or drum boiler.
3. The water-tube boiler.

THE RECTANGULAR BOILER.

The Rectangular Boiler shown in Fig. 1 is made square or box-shaped; hence the sides are flat. This form was one of the earliest used; at present, however, its use is restricted to low pressure, that is, under 30 pounds per square inch. The reason why this boiler cannot be used for high pressure is that the flat plates tend to bulge outward when under high pressure. In order to prevent the plates from bulging they must be stayed with numerous longitudinal and vertical stay rods.

Box boilers were generally made with an internal uptake as shown in Fig. 1. This construction permits of a larger steam space and reduces loss of heat by radiation. It is, however, expensive in first cost and repairs; also the plates of the uptake waste rapidly, especially near the water line, because the heat is not transmitted as readily by steam as by water. In case the uptake is made separate and does not form a part of the boiler, this objection is avoided.

The tubes of the rectangular boiler are usually horizontal or nearly so. When set inclined or with a "rake," as it is called, there is more room for manholes at the smoke-box end.

The extremities of the tubes at the combustion chamber end are near the furnace but are higher at the smoke-box end. The water level is about the same as with the horizontal tubes; the ends nearest the combustion chamber having the greater depth of water over them. The inclination is about one inch to the foot

Rectangular boilers were made in two ways, and from the form of construction were known as **wet bottom** and **dry bottom.** The wet bottom boilers were made with the furnace wholly inside and independent of the shell; the furnaces being surrounded by water on all sides. In the dry bottom boiler, the furnaces terminated in the boiler shell at the bottom, having a water space called the water leg between them. This water leg causes trouble by getting filled up with sediment. A furnace had water around the sides but like the locomotive and most vertical boilers, there was no water underneath.

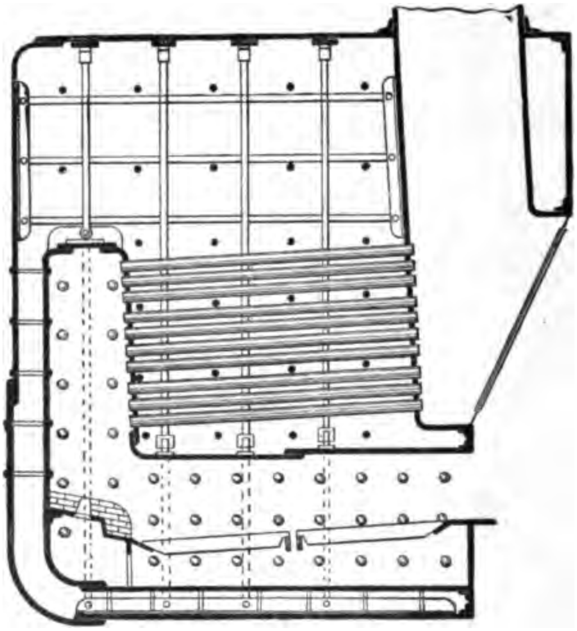


Fig. 1.

The dry bottom boiler is lighter, (as the bottom plates are omitted), cheaper, has greater durability and is easier to examine. On the other hand it is more dangerous to the ship, as the heat is likely to cause corrosion of the frames if of iron, or burn the frames if of wood. The wet bottom boiler is very difficult to inspect and repair.

In order to avoid the large number of stays in the steam space, for pressures over 30 pounds per square inch, the oval boiler was introduced. It has semi-cylindrical top and bottom and flat sides. This form was soon abandoned because it would stand only about 45 pounds pressure.

THE CYLINDRICAL BOILER.

Next after the oval boiler came the cylindrical. This boiler is made with the shell a complete cylinder. It is lighter, cheaper and more easily made than the rectangular. It occupies more space and for a given heating and grate surface has a smaller steam space. Cylindrical or Scotch boilers may be divided into three classes as follows:

1. Single ended boilers.
2. Double ended boilers.
3. Gunboat or through tube boilers.

THE SINGLE ENDED BOILER.

The single ended, return tube boiler, has furnaces and tubes only at one end. The arrangement of furnaces and flues is similar to that of the Lancashire boiler. The single ended marine boiler, shown in section in Figs. 2 and 3, is often made very large; sometimes 17 feet in diameter and 12 feet long.

The **shell** is made up of belts of wrought iron or mild steel. They are fastened together by being riveted where the edges overlap.

The **front** and **back** are made up of flat circular plates. The edges are flanged and riveted to the shell plates.

The **furnaces** are cylindrical, 3 feet to 4 feet in diameter and about 7 feet long. The front ends of the furnace flues are riveted to flanged holes in the front plate; the back ends are riveted to the combustion chamber. These flues are not made plain cylinders because a plain cylinder, unless small, cannot stand high pressure. Furnace flues are usually made with ribs or corrugations.

The **combustion chamber** is formed of flat and curved plates flanged at the edges and riveted together. The form is shown in Fig. 2. The flat sides are fastened to the back and shell plates by short stay bolts. The back tube sheet forms one side of this chamber. Since the space in the flues is small the combustion chamber is made sufficiently large to allow complete combustion of the hydro-carbons driven out of the fuel by the heat of the fire.

Grate Surface. The two lengths of grate bars, which form the grate surface, divide the furnace flues into two parts. The coal is burned on the bars, the fire occupying the portion above them. The space below the grate is called the **ash pit.** Air enters the ash pits and then passes up through the spaces of the grate bars to the coal.

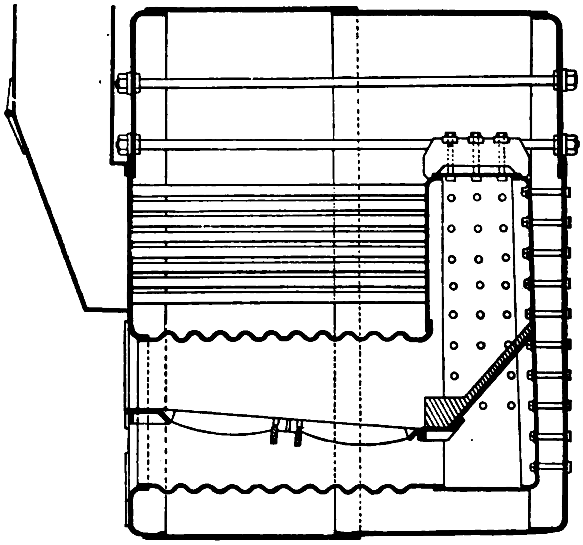


Fig. 2.

The furnace doors. The furnaces are fitted with doors through which fuel is supplied to the fire. The doors are usually provided with gratings which allow air to pass to the top of the fuel. The ash pit also has doors which are called **ash pit doors** or **draft plates.** These draft plates serve to regulate the supply of air to the ash pit. The furnaces, if corrugated, must be fitted with **ash pans** to enable the ashes to be drawn out readily. These ash pans protect the grates from wear caused by the constant use of the hoe.

Bridge. The back of the furnace is formed by the bridge, which is usually built of fire brick.

Tubes and Heating Surface. The tubes of the marine boiler are similar to those of the horizontal multitubular boiler. They are expanded into the front plate and the rear tube plate. The tubes form a large heating surface in a small space. The heating surface of the boiler is made up of the tubes, tops of furnaces, and top and sides of the combustion chamber. The tubes, however, furnish the greatest amount.

The **water level** is about 6 to 8 inches above the top row of tubes; the space above the water level is called the steam space and the part below, the water space.

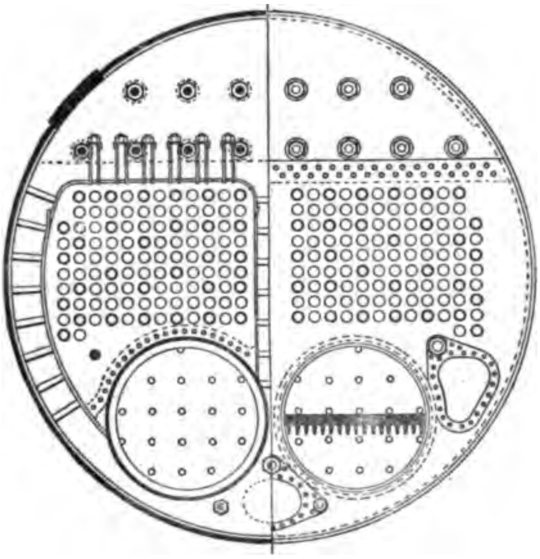


Fig. 3.

Stays. All the flat or nearly flat plates of the boiler and combustion chamber must be stayed to prevent bulging and collapsing. The flat ends above the water line are stayed by means of long stay rods, similar to those of a multitubular boiler. The ends are provided with large washers to distribute the pressure over a large area. The combustion chamber plates are supported by short stay bolts secured by nuts. The top plate of the combustion chamber is supported by girders or crown bars; sometimes called "dogs." The tubes act as stays for the tube sheets, but it is usual to put in a few tubes thicker than the rest, so that they may be screwed into the tube sheets and secured by thin nuts on both sides of the plate. The stay tubes of Fig. 3 are indicated by the heavier circles. Sometimes solid bars or blind tubes are used in place of stay tubes.

Manholes. For examining and repairing the interior of a boiler, manholes and handholes are provided where necessary. These manholes are similar to those of the multitubular boiler.

The **size and number of furnaces** depend upon the size and heating surface of the boiler. The large boilers usually have three or four furnaces and the smaller ones have two. Large furnaces are more efficient than small ones because the grate area increases directly as the diameter, while the air spaces above and below the grate increase as the square of the diameter. This greater space together with the greater inclination of the grate bars aids combustion. The length of the grate bars is nearly constant for all sizes of flue. It has been found by practice that furnace flues should be between 36 and 54 inches in diameter. Then boilers of one furnace may be made up to 9 feet in diameter, and those over 15 feet diameter should have four furnaces. The great difficulty in designing such large boilers is to provide sufficient grate area for the large heating surface; hence for large diameters four furnaces are used to avoid excessive length of grate.

The furnace flue leads to a combustion chamber from which the products of combustion return to the front of the boiler through the tubes to the uptake.

A single furnace boiler has one combustion chamber. A two furnace boiler may have a combustion chamber for each furnace or a common combustion chamber. In case there is but one boiler in the ship it is better to have two combustion chambers, so that in case a tube bursts the boiler will not be disabled. If, however, there are several boilers, it is better to have a common combustion chamber for the two furnaces, because the alternate stoking keeps up a more steady supply of steam and also consumes the smoke. Three furnace boilers usually have three combustion chambers and four furnace boilers generally have two. If three combustion chambers are used with four furnaces, the two more central furnaces lead to one only, while each of the outside furnaces has one. In designing a marine boiler the number and size of the flues is important. Large flues are likely to collapse under external pressure, but they allow a large grate. In using a greater number of smaller furnace flues instead of larger ones, the necessary grate area can be obtained.

THE DOUBLE ENDED BOILER.

This type of boiler has furnaces in both ends with return tubes over them similar to the single ended boiler. It is practically equal to two single ended boilers placed back to back but having the rear plates removed. By thus saving the extra weight of the back plates and reducing the radiating surface a double ended boiler is lighter and cheaper in proportion to the total heating surface than a single ended boiler. The double ended boiler is often made 18 feet in diameter and about 16 feet long. There are two distinct classes of double ended marine boilers; those having all the furnaces open into one combustion chamber and those having several combustion chambers.

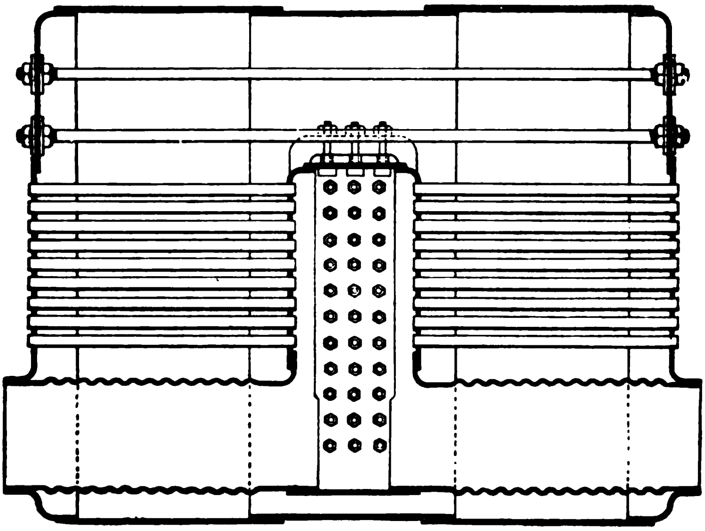


Fig. 4.

The boiler with one common combustion chamber is not very common at present. If one furnace is being cleaned the whole boiler is cooled by the rush of cold air. This is the chief objection to its more general use.

A better form is that shown in Figs. 4 and 5. The opposite furnaces have a combustion chamber in common ; that is, the combustion chambers, as in Fig. 5, are separated longitudinally by water spaces. Thus the boiler in Fig. 5 has three combustion chambers since it has three furnaces. This kind of boiler is considerably used because it avoids the faults of the single combustion chamber but retains the good features of the double ended boiler. Considerable care is necessary when raising steam because the tubes are likely to leak on account of the unequal expansion of the tube sheet. A brick bridge wall called the arch or deflector built in the middle of the combustion chamber prevents the cold air from rushing against the opposite tube plate.

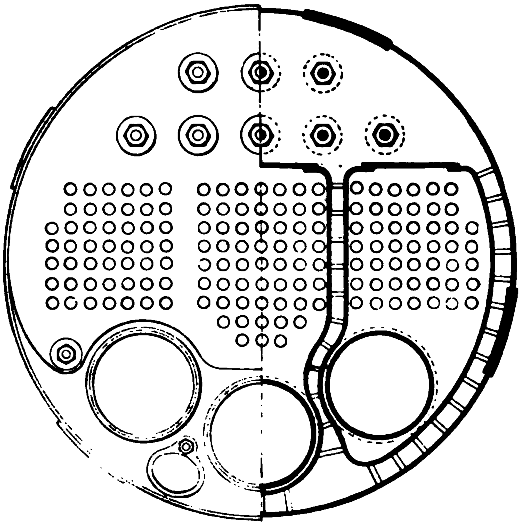


Fig. 5.

Another common form of double ended boiler has two combustion chambers. The furnaces at either end have a common combustion chamber; these latter being separated by a water space. The backs of the combustion chambers thus formed are large and flat, and on account of the large number of stays are difficult to clean. In vessels of the navy the boilers are generally made with a combustion chamber for each furnace. This form is shown in Figs. 6 and 7, which are sections of one of the boilers of the U.S.S. "Texas." This type is the heaviest and most expensive.

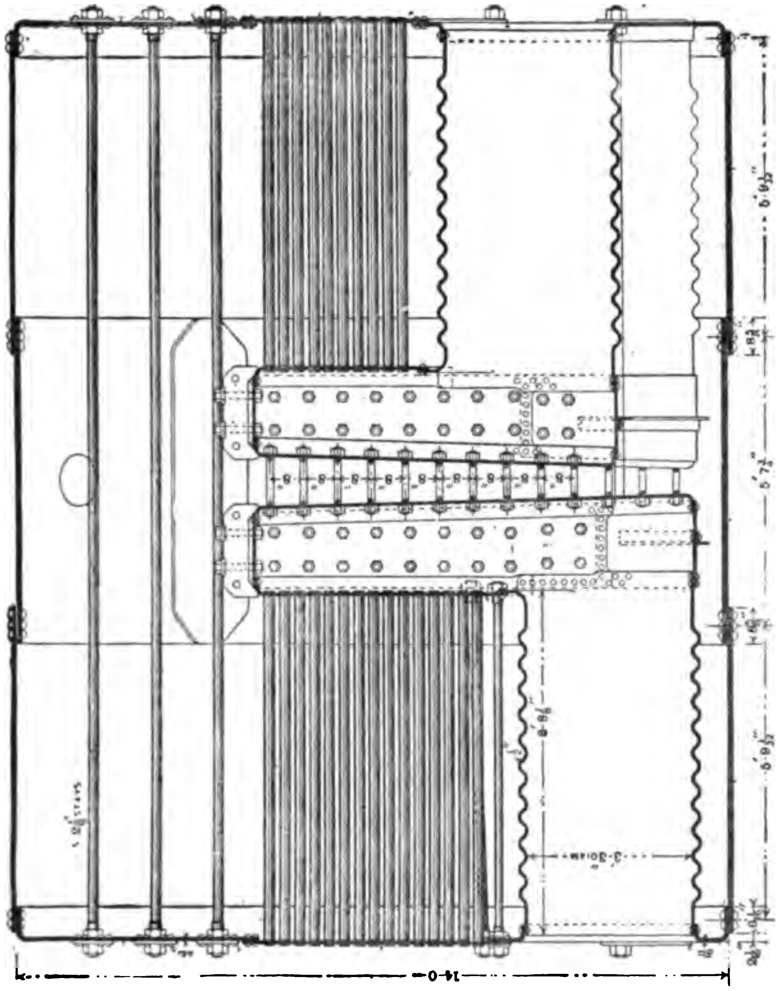


Fig. 6.

It is similar to two single ended boilers, as it has separate combustion chambers for each furnace.

GUNBOAT BOILERS.

In gunboats and other vessels of slight draft there is not sufficient room for a return tube boiler. The boilers used in these vessels are of a particular type and suited to the requirements. The boiler shown in Fig. 8 resembles both the cylindrical boiler and the locomotive boiler. It is cylindrical and in external appearance like the return tube boiler, except that it is longer and of less diameter. The fire is in a flue which leads to a combustion chamber. The hot gases pass from the combustion chamber through a nest of small tubes to the uptake at the front. Sometimes a hanging bridge in the combustion chamber deflects and retards the hot gases. This boiler burns coal freely and evaporates water quickly and efficiently. The chief objections are the small heating surface for the space occupied and the great length.

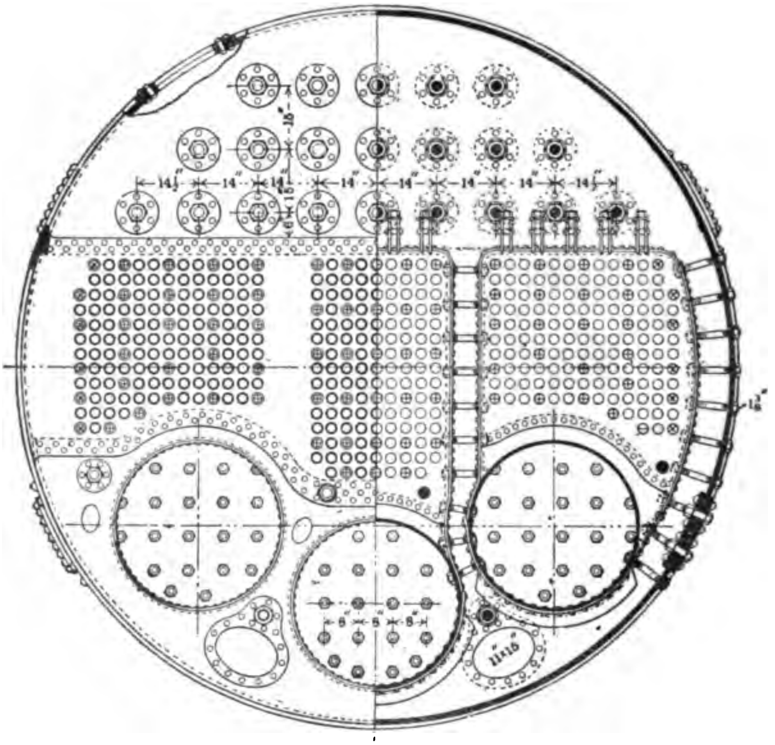


Fig. 7.

Locomotive Boilers. This boiler was used for launches and torpedo boats. It was a convenient form and a very light boiler for the heating surface. With it forced draft was almost invariably used on account of the small grate area. The furnace crown, being flat, requires careful staying.

Let us leave the consideration of the water-tube boilers until we have finished the cylindrical.

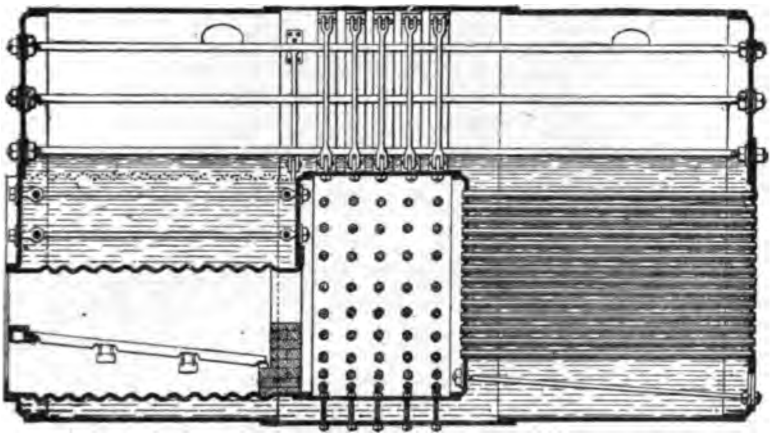


Fig. 8.

MATERIALS.

In marine work, the weight of boilers and engines is important. In the navy especially, the machinery must be as light as is consistent with strength. By using material that is very strong and durable the marine engineer is able to reduce the weight of the machinery. The great advance made within the last few years is largely due to the use of superior materials. Steel, which was formerly very scarce and expensive, is now made at such a slight cost that it is rapidly taking the place of iron for most engineering purposes.

The materials used for boilers are briefly described in "Construction of Boilers." The method of converting cast iron into wrought iron and steel and the various properties of these metals are discussed in "Metallurgy."

The *steel* used for boiler construction is made by the Bessemer and Siemen's processes. Experiment shows that the higher the tensile strength, the lower the elasticity. Steel for boiler shells usually has an elongation of about 15 to 25 per cent. and a tensile strength of 45,000 to 60,000 pounds per square inch. For the internal portions of the boiler, the material should be somewhat softer in order that it may be flanged and stand the wear and tear of manufacture.

In order to know that the materials have the proper qualities,

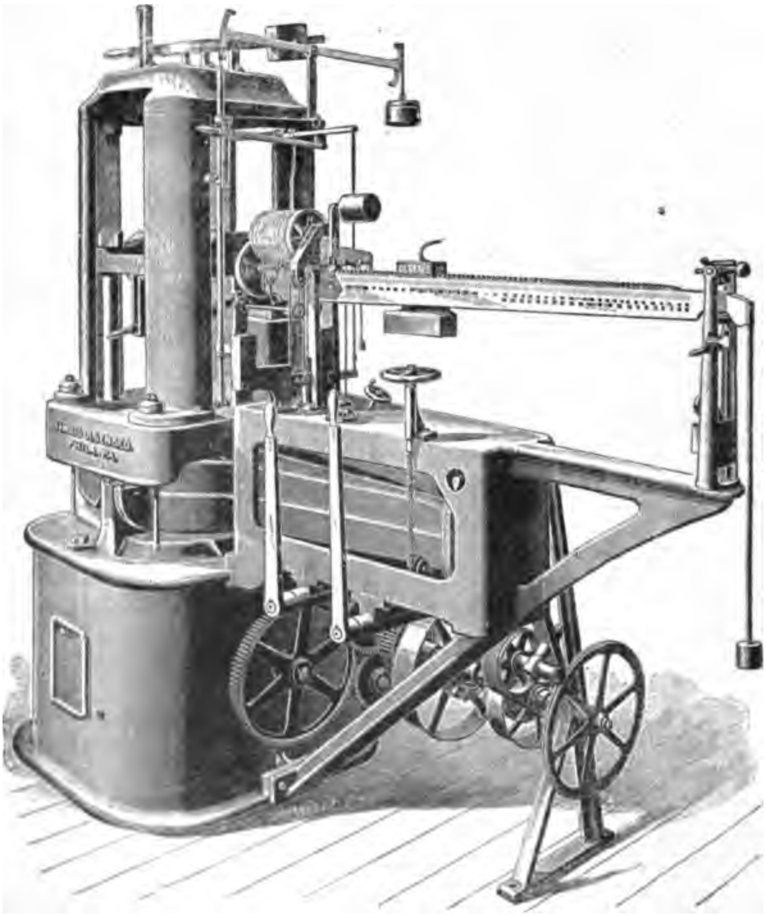


Fig. 9.

specimens are tested. The results of these tests show the ultimate tensile strength, elastic limit, contraction of area and elongation.

The simplest way to test a piece of iron bar or plate would be to fix it firmly at the upper end and hang weights on the other end, adding other weights until the bar is broken. This is but a crude method, and in order that the elastic limit and elongation may be determined with the tensile strength, testing machines are used. There are a large number of testing machines in use but the general principles are the same.

Testing Machines. The frame of a testing machine has two heads, to which the ends of the test piece are fastened by wedges or other devices. One head is drawn away from the other for tensile tests. The pull is transmitted to some weighing device, usually levers and knife edges like the beam of ordinary platform scales. The power causing the pull may be applied by a lever, by hydraulic power, or by steam.

Testing machines are made for all varieties of testing ; tensile, compressive and shearing stresses. Also for deflection of beams and for strength of wood, cement, brick and stone. Fig. 9 shows an Olsen testing machine designed for tensile and compressive tests of iron and steel.

In order to test materials test pieces or specimens are made.

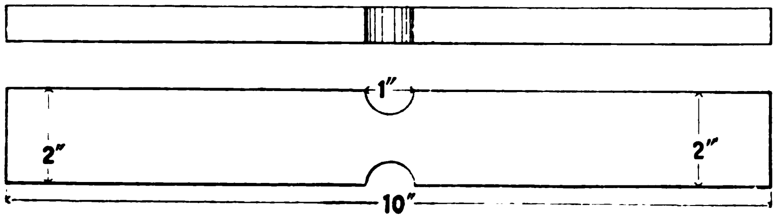


Fig. 10.

For testing **iron plate** the test piece should be at least one inch wide, about two feet long and planed on both edges. Many engineers recommend these dimensions; but, according to the Board of Supervising Inspectors of Steam Vessels, the test piece should be 10 inches long, 2 inches wide and cut out at the center, as shown in Fig. 10. According to their rules, the width of plate at this reduced section shall be 1 inch if the plate is $\frac{5}{16}$ inch or under; if any other thickness, the area of cross-section shall approximate $\frac{4}{10}$ of one square inch. It shall not exceed .45 square inch nor be less than .35 square inch. The force necessary to break the piece is taken as the proportionate part of the tensile strength per square inch. Thus if the test piece having a reduced section of .4 square inch is broken at 19,200 pounds, the tensile strength of the plate is $\frac{19,200}{.4} = 48,000$. If the tensile strength so determined equals the tensile strength as stamped on the plate, the plate can be used in the construction of marine boilers.

To ascertain the tensile strength and other qualities of **steel,** a test piece should be taken from each plate. These test pieces are made in the form as shown in Fig. 11. The straight part in the center is 9 inches long and 1 inch wide; and, to determine elongation it is marked with light prick punch marks at distances 1 inch apart; the marked space being 8 inches in length. The ends are from 1½ to 2 inches broad and 3 inches to 6 inches long.

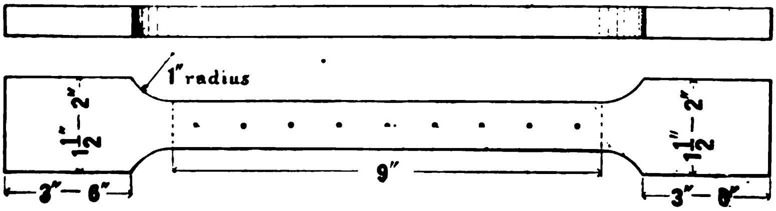


Fig. 11.

According to the Rules of the Board of Inspectors, the sample must show, when tested, an elongation of at least 25 per cent. in a length of two inches for a thickness up to and including ¼ inch. It must have the same per cent. of elongation in 4 inches if the plate is over ¼ inch to $\frac{7}{16}$ inch thick inclusive. For all plates over $\frac{7}{16}$ inch up to 1¼ inches thick the sample must show an elongation of 25 per cent. in 6 inches.

No iron or steel plate having a tensile strength of less than 45,000 pounds is allowed in the construction of any part of a marine boiler. Among other rules of the same Board are found the following:

"Iron of 45,000 pounds tensile strength shall show a contraction of area of 15 per cent. and each additional 1,000 pounds tensile strength shall show 1 per cent. additional contraction of area up to and including 55,000 pounds. Iron of 55,000 T. S. and upwards showing 25 per cent. reduction of area shall be deemed to have the lawful ductility. All steel plate of ½ inch thickness and under shall show a contraction of area of not less than 50 per cent.

Steel plate over ½ inch in thickness, up to ¾ inch in thickness shall show a reduction of not less than 45 per cent. All steel plate over ¾ inch thickness and less than 1¾ inches in thickness shall show a reduction of not less than 32.5 per cent."

"No plate shall contain more than .06 per cent. of phosphorous and .04 per cent. of sulphur, to be determined by analysis by the manufacturers."

"The samples shall also be capable of being bent to a curve of which the inner radius is not greater than 1½ times the thickness of the plates after having been heated uniformly to a low cherry red and quenched in water of 82° F."

In testing material of other forms than plate, a stay rod for instance, it is better to test a sample of the whole forging if the testing machine is of sufficient capacity. If, however, the machine is too small the test specimen may be made in the form of a bar about 1 inch in diameter and 18 inches long having the central portion turned down to a diameter of about ⅝ to ¾ of an inch. The turned portion should be about 9 inches long in order that the prick punch marks for determining elongation may be made as described with Fig. 11.

For testing the compressive strength of iron and steel it is usual to take a short cylinder of the material usually about an inch in diameter and a length equal to three diameters or less. If the specimens are long they will give way by bending rather than by crushing. In most commercial tests the elongation is taken as the indication of ductility, as the reduction of area can not be found as accurately without considerable difficulty.

In testing for tensile strength, the results calculated from the data are,

1. *Tensile strength* in pounds per square inch of original area.

2. *Elongation*, per cent. of a stated length (usually 8 inches), between gage marks.

3. *Elastic limit* in pounds per square inch of original area.

Stress. The number of pounds of force applied per square inch is called the stress. If the piece is under direct tension or compression the stress is considered uniform and is equal to the load divided by the area of the transverse section. Thus, if the section of the plate is 1″ by $\frac{7}{16}$″ and the actual stress is 17,750 pounds the stress per square inch is $\frac{17,750}{.4375} = 40,570$ (about) pounds.

Ultimate Strength. The maximum stress that a test piece will stand is called the ultimate strength. For ductile materials the breaking stress is considerably less than the ultimate stress. That is, when the loads are gradually applied the total load will reach a maximum and then the metal stretches so that at the moment of rupture the load is much less than the maximum. The strength of iron and steel depends somewhat upon the rate of testing; the more rapid the application the higher the stress as recorded by the scale beam.

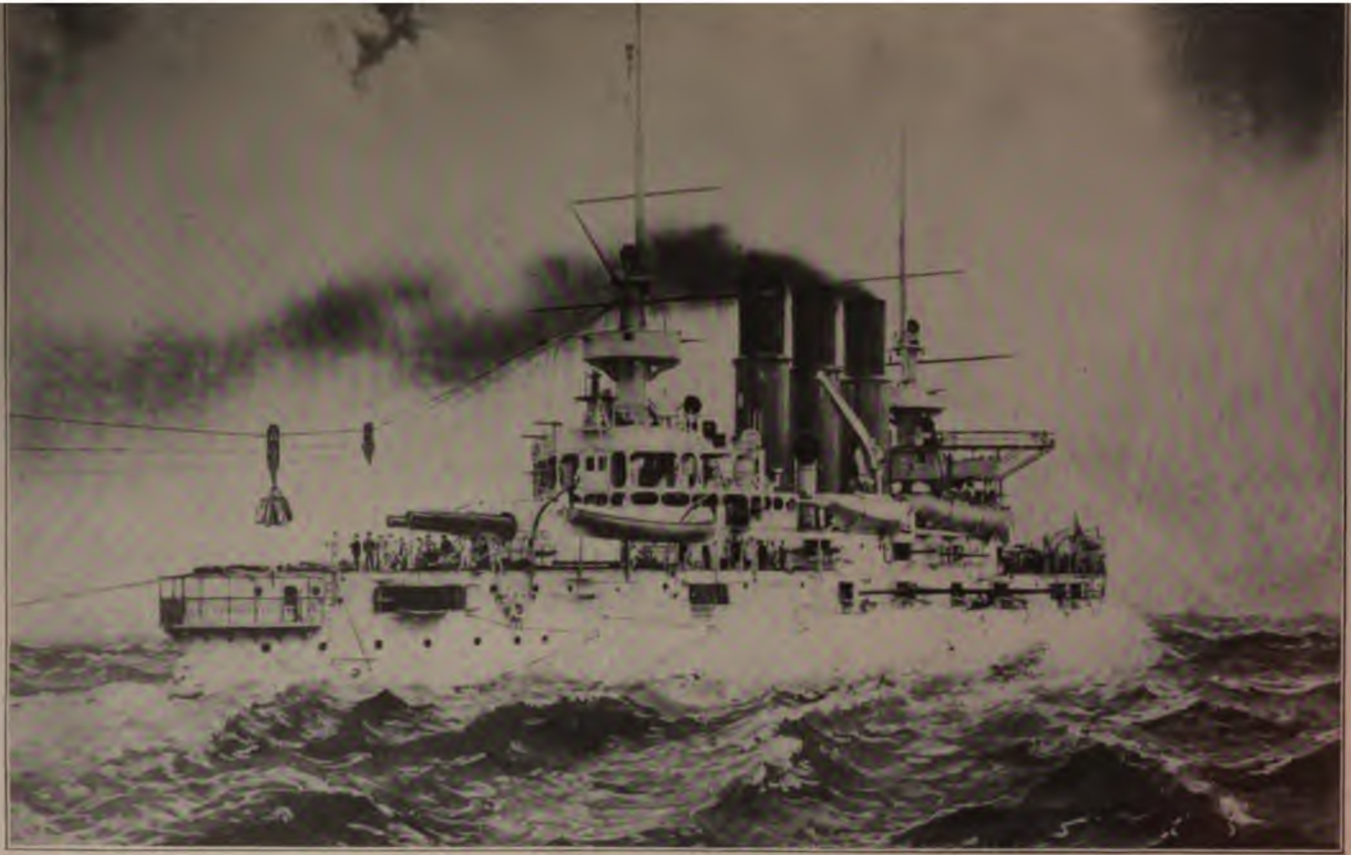
Strain is the stretch per unit of length of the test piece when in tension. If the original length is L, and the stretch or elongation is B, the strain becomes $\frac{B}{L} = b$.

Elastic Limit. When testing a piece, at first the stress and strain are proportional. The point at which the strain or stretch begins to increase more rapidly than the stress is called the elastic limit. This limit is not definite; it can be determined approximately only. A load greater than the elastic limit will produce a permanent elongation.

Stretch Limit is the stress at which the scale beam of the testing machine will fall while the straining head is at rest.

Reduction of Area. When a test piece ruptures the area at that point is much less than the plate or bar before testing. This reduction shows the ductility of the material; it also shows the property of changing shape without actual rupture. This is important in boiler construction.

Elongation. Ductile materials stretch before breaking. To measure the ultimate elongation the two broken pieces are placed in a straight line with the broken ends in contact. The length between points can be measured. It is usual to use 8 inches as this distance. As the prick punch marks are made before testing, the elongation is easily determined. The ratio of the elongation to the original length is called the ultimate elongation. Suppose the distance between the extreme prick punch



RUSSIAN BATTLESHIP RETVIZAN.

Sunk by Japanese Torpedo in first attack on Port Arthur, Feb., 1904, at outbreak of Russo-Japanese War.

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marks is 8 inches before testing and $9\frac{7}{8}$ inches after. Then the bar or plate has stretched $1\frac{7}{8}$ inches. The ultimate elongation is $1\frac{7}{8} \div 8 = .234$ or 23.4 per cent.

These various properties of materials may be shown by **diagrams.** Fig. 12 shows the diagram for wrought iron and steel when under tension. The unit stresses are taken as ordinates and the unit elongations as abscissas. For each stress the corresponding elongation, as found by the testing machine, is laid off. The curve is drawn through these points. Each specimen has its own curve, those shown in Fig. 12 being plotted from average values. Since stress and elongation are proportional up to the elastic limit, the curve from the origin to the elastic limit is a straight line.

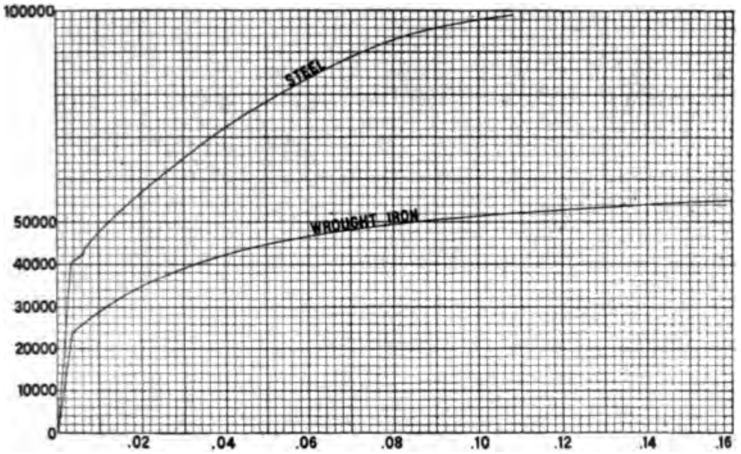

Fig. 12.

At the elastic limit the curve changes suddenly and the elongation increases rapidly. From the elastic limit to the point at which the piece breaks the stress is not proportional to elongation. The end of the curve indicates the point of rupture. Curves show the properties of various materials. It is seen that the elastic limit is not well defined but can be estimated very nearly. These curves may be plotted from results of tests or they may be drawn automatically by the testing machine.

Steel for boiler construction should have the following properties.

Tensile strength	50,000 to 60,000 lbs.
Elastic limit	30,000 to 35,000 lbs.
Reduction of area	50 per cent. or more.
Elongation in 8 inches	25 per cent. or more.

The mechanical tests are given in "Construction of Boilers."

BOILER CONSTRUCTION.

Shell. As the cylindrical boiler is the strongest form to resist internal pressure, it is most extensively used. For this reason we will consider the construction of the cylindrical Scotch boiler.

Boiler shells are composed of plates with riveted seams. If steel is used the plates may be placed either lengthwise or crosswise with the circumference; if of iron, the plates should be arranged so that the fibre will extend around the circumference as iron is stronger in the direction in which it is rolled.

RIVETING.

Rivets are made from bars of tough ductile iron or mild steel. These bars are cut to the proper length and each piece is placed in dies which form the tail. The tails of rivets are of various shapes depending upon the kind of riveting, the pan-shaped shown in Fig. 13, and the cup-shaped shown in Fig. 14 being the most common. The cylindrical portion called the shank is tapered for about one-half the length in order to enter the holes easily. The proportions of rivets vary and there are no standard sizes.

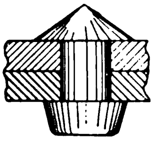
Fig. 13.

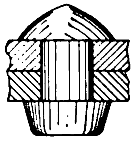
Fig. 14.

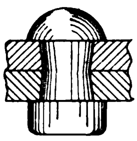
Fig. 15.

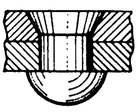
Fig. 16.

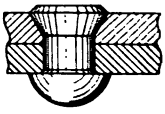
Fig. 17.

The heads of rivets are formed by knocking down the point of the shank with a hammer or by means of a riveting machine. Heads made by hand are usually conical or cup shaped, as shown in Figs. 13 and 15. Fig. 14 shows a conoidal headed rivet. Countersunk rivets are shown in Figs. 16 and 17. Rivets are tested mechanically as briefly described in "Construction of Boilers."

Circumferential or ring seams are usually **lap joints** since the tendency to rupture at these seams is only one-half as great as at the longitudinal seams.

These latter are usually double riveted and for high pressures treble riveted. Lap joints are constructed by making one plate overlap the other and riveting them together. Fig. 18 shows the most simple form of this joint and is called a single riveted lap joint. Double riveted lap joints may have the rivets arranged as shown in Figs. 19 and 20. The former joint is called a double riveted lap joint with chain riveting, and the latter a double riveted lap joint with zigzag riveting. The zigzag riveting is a little weaker than the chain, but the joint is usually tighter and less lap is required.

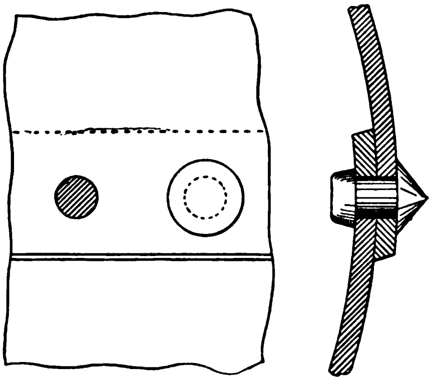

Fig. 18.

The *efficiency* of lap joints depends upon the pitch of the rivets, the diameter of the rivets, the thickness of plates and the number of rows. The efficiency is also somewhat altered if the plates are drilled instead of punched. As there are so many conditions we can give only rough average efficiencies.

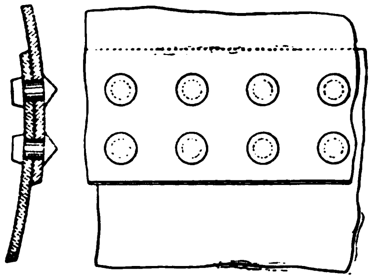

Fig. 19.

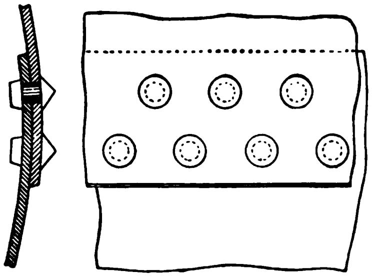

Fig. 20.

Lap joint, single riveted, efficiency about 56%.
Lap joint, double riveted, efficiency about 70%.
Lap joint, treble riveted, efficiency about 72%.

The probable efficiency of joints may be calculated by mathematics, but the actual efficiency can be obtained only by means of the testing machine. In testing, a piece of uncut plate (the size of which depends upon the capacity of the machine) is first tested. Then a portion of the joint of approximately the same size is then tested. The ratio of the breaking strength of the joint to that of the uncut plate is the efficiency.

Longitudinal seams are almost always made with the **butt joint.** These joints are seldom single riveted because they are no stronger than a double riveted lap joint and are more expensive. If, however, they are made with double butt straps and double or treble riveted, the joint shows a high efficiency. The two butt straps may be of the same width or the inner may be wider than the outer. Fig. 21 shows a double riveted butt joint with two butt straps. A treble riveted butt joint is shown in Fig. 22. The following are approximate efficiences:

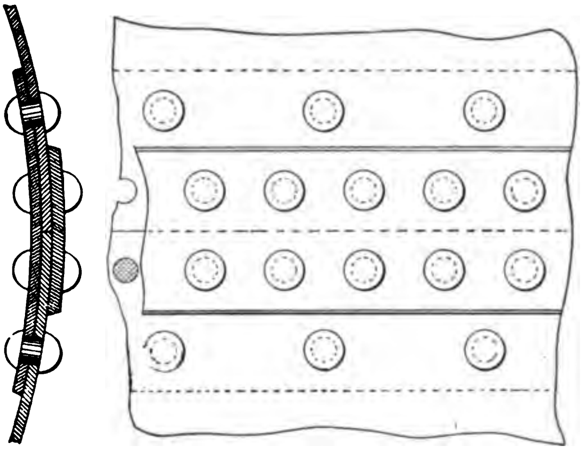

Fig. 21.

Butt joints, single riveted, efficiency about 65%.
Butt joints, double riveted, efficiency about 75%.
Butt joints, treble riveted, efficiency about 85%.

Butt straps are usually about the thickness of the shell plates.

FLANGING.

End plates and nearly all the internal plates of a marine boiler are flanged. This operation is likely to weaken the plates, if not crack them. Ductile iron and steel can, with proper care and good machinery, be flanged with little danger of spoiling the plates. In flanging, the plates are heated locally which causes internal stresses to be set up: these stresses can be almost entirely removed by annealing. When flanging the holes for the furnaces in the end plate, care must be taken to prevent distortion of those flanged while the others are being operated upon. The danger is prevented if all the holes are flanged at once but this process requires heavy machinery. When flanging end plates the material is likely to become thin at the curved portions ; to prevent this suitable moulds should be used and the heat regulated carefully.

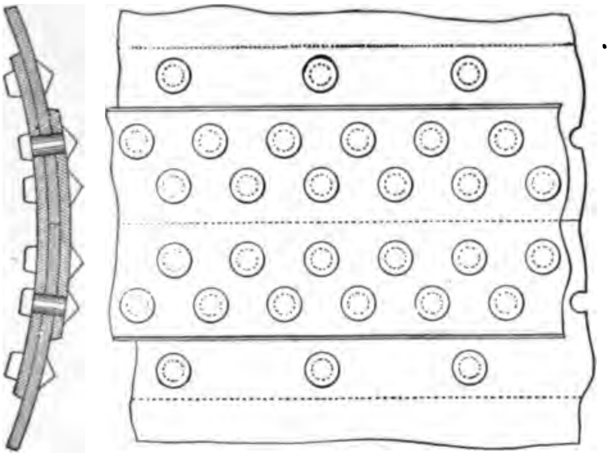

Fig. 22.

STRENGTH OF SHELL.

The rules for the construction of the various parts of the marine boiler as given by engineers, writers and legislation do not agree. If a boiler is made in England it must conform to the rules of the Board of Trade or Lloyd's Registry. For boilers built in the United States the rules given by the Board of Supervising Inspectors of Steam Vessels must be followed. In the Navy, boilers are constructed from rules by the Naval Department or from a special act of Congress. The above rules differ somewhat, but all boilers must have parts which do not vary much from the requisite size.

As stated in "Construction of Boilers," the shell tends to rupture longitudinally; the resistance being the two sections of metal at the sides.

In "Construction of Boilers" we stated the following formulas for the strength of shell,

$$p = \frac{2\,t\,\mathrm{S}\,\mathrm{E}}{f\,\mathrm{D}},$$

$$t = \frac{f\,\mathrm{D}\,p}{2\,\mathrm{S}\,\mathrm{E}}.$$

p = working pressure in pounds per square inch.
t = thickness of shell in fractions of an inch.
S = tensile strength of material.
f = factor of safety.
D = diameter of boiler in inches.

This formula is the same as that given by the English Board of Trade.

Suppose a single ended Scotch marine boiler is 13 feet 6 inches in diameter. The shell plates are $1\frac{1}{32}$ inches thick and the joints have an efficiency of .81. If the tensile strength is 60,000 pounds and a factor of 4.5 is used what is the working pressure?

$$\begin{aligned} p &= \frac{2\,t\,\mathrm{S}\,\mathrm{E}}{f\,\mathrm{D}} \\ &= \frac{2 \times \frac{33}{32} \times 60{,}000 \times .81}{4.5 \times 162} \\ &= 137.5 \text{ pounds.} \end{aligned}$$

The formula given by the Board of Supervising Inspectors of Steam Vessels is, using the notation above,

$$p = \frac{t \times 2 \times \mathrm{S}}{6 \times \mathrm{D}}.$$

Add 20 per cent. if the longitudinal seams are double riveted.

Then for the boiler whose dimensions are given above, the working pressure is,

$$p = \frac{\frac{33}{32} \times 2 \times 60{,}000}{6 \times 162}$$

$= 127.3$ and 20 per cent. additional gives $p = 152.76$.

This formula does not allow for the kind of joint, the only distinction being single and double riveting.

Factor of Safety. A steam boiler should be very strong in order to provide for defects in material and workmanship, wear and tear of manufacture, and when under steam, wasting by corrosion. For these reasons there should be considerable difference between the working pressure and the bursting pressure. This difference, or the ratio in which the bursting pressure exceeds the working pressure is called the factor of safety. When the material and workmanship is moderately good the factor may be about 6. In case the material is good, the boilers well made and cared for but not often inspected the factor should be about 5. If material and workmanship is high class, the boilers well made and regularly inspected the factor may be about $4\frac{1}{2}$. The factor should never be less than 4.

End Plates. There are several methods of connecting the end plates to the shell. Those methods which use a flanged end plate are by far the best. The flange is usually placed inward as shown in Fig. 23; but for small boilers it is sometimes placed outside, shown in Fig. 24, to facilitate riveting. In some cases the shell plates are flanged. This has some bad features among which may be mentioned; the difficulty of flanging the thick plate, the tendency of the pressure to straighten out the flange and the low strength necessary for the desired ductility.

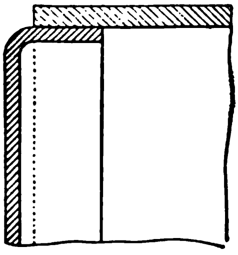
Fig. 23.

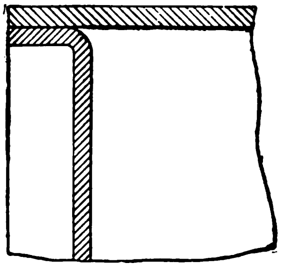
Fig. 24.

The quality of iron or steel for end plates depends upon the amount of flanging to be done. If the circular edges and the holes for the furnaces are to be flanged the material should be very ductile to prevent injury. The thickness of the end plates is less than that of the shell plates. It is dependent upon the pitch of the stays; the end is usually made up of two or three plates. As the pitch of the stays in the steam space is greater than that of the tubes the end plate of the steam space should be thicker than the tube sheet. However, they are often made the same thickness and the top plates stiffened by large washers. End plates are from $\frac{9}{16}$ to $\frac{3}{4}$ inch thick. Sometimes they are made thicker in order to avoid fitting nuts and washers to screw stay bolts, and the heavy reinforcing about manholes.

FURNACES.

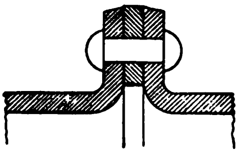

Fig. 25.

In the rectangular boilers the furnaces were made square or rectangular having the corners rounded. This form is not suitable for high pressures so the furnaces of Scotch boilers are always made cylindrical as it is the best form to resist uniform external pressure. The furnace flues should be as thin as the external pressure will permit. Thick plates are more likely to blister and become injured by heat than thin ones. A mild quality of steel is perhaps the best material to use. It is important that the furnaces should be as nearly a true circle as possible, as any deviation causes a great increase of deformity through external pressure.

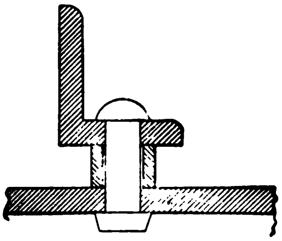

Fig. 26.

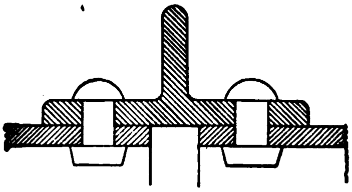

Fig. 27.

In "Construction of Boilers," Fairbain's formula for the strength of flues is given. The formula for long furnaces given by the Board of Supervising Inspectors of Steam Vessels is,

$$P = \frac{89,600 \times t^2}{L \times D},$$

in which P = working pressure in pounds per square inch, t =

thickness of flue in inches, L = length in feet and D = outside diameter in inches. In this formula L is not to exceed 8 feet.

In case the flue is made with rings riveted to the flue, L is taken as the distance between rings.

What is the allowable pressure on a furnace flue 6 feet long, 42 inches in diameter and $\frac{1}{2}$ inch thick?

$$P = \frac{89{,}600\, t^2}{L \times D} = \frac{89{,}600 \times .25}{6 \times 42} = 88.9 \text{ pounds.}$$

Furnace plates are made from $\frac{3}{8}$ inch to $\frac{3}{4}$ inch in thickness, $\frac{7}{16}$ to $\frac{9}{16}$ being common.

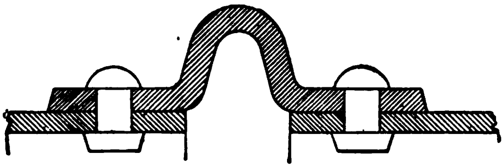

Fig. 28.

If $\frac{9}{16}$ inch is not sufficiently thick for the length some means of strengthening is employed.

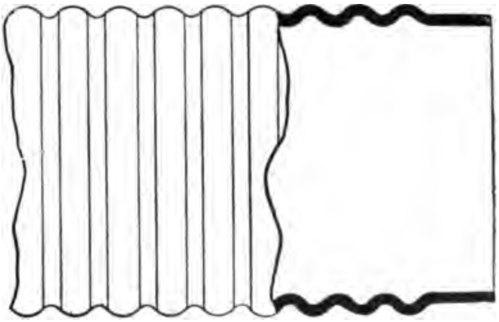

Fig. 29.

A section of Adamson's flanged seam is shown in Fig. 25. On the end of each belt external flanges are formed which are riveted together with a wrought iron ring between them. The radius of the flanges should not be less than $\frac{3}{4}$ inch and a greater radius is better. This form of joint makes the flue rigid circumferentially and elastic longitudinally. Fig. 26 shows the section of a ring made of angle iron. This ring is about 3″ × 3″ × $\frac{1}{2}$″. The ring is riveted to the flue at intervals; ferrules being placed between so that the water space is about 1 inch. Sometimes the ring is made in two parts and bolted together. Another method is to make them in one piece and weld the ends. The section of a welded ring of T iron is shown in Fig. 27. The ring is riveted to the ends of the flue sections which are not flanged. This method provides for calking on both inside and outside. Such a form of joint does not require flanging; but as flanging is easily done with modern machinery and all good boiler plate will stand it, these forms do not offer that advantage. The best form for longitudinal expansion is that shown in Fig. 28, called the bowling hoop ring.

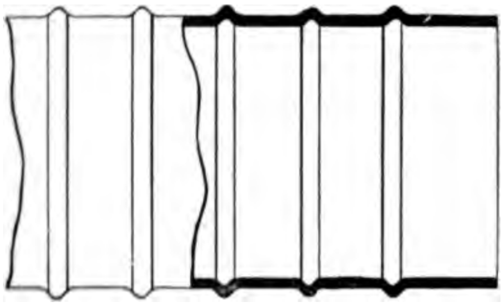
Fig. 30.

All these forms except the Adamson's ring have joints so arranged that the rivet heads are exposed to the fire. They have also the disadvantage of the projecting rings which prevent the flues from being placed near the shell plates.

To overcome the above disadvantage, the furnace flues are forged with **corrugations** or ridges. Perhaps the most used form is that called the Fox furnace shown in Fig. 29. These corrugations are about 6 inches center to center and $1\frac{1}{2}$ inches deep. Another form of furnace is the Purves, shown in Fig. 30. The The Morison furnace is shown in Fig. 31, and the Holmes in Fig. 32. These furnace flues are made on the principle of the bowling hoop but with the hoop not separate from the plates. The Holmes has few corrugations and is rigid longitudinally but is not as strong to resist pressure as the Fox; consequently the latter may be made thinner than the former. A corrugated furnace has about 25 per cent. more heating surface than the plain

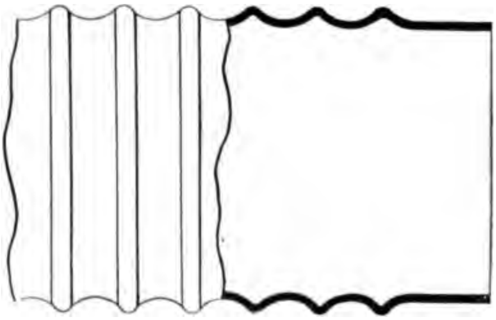
Fig. 31.

flue. On account of the expansion and contraction, scale is loosened from the corrugations of the Fox furnace; hence it is called a "self-cleaner" of scale.

The formula for the working pressure for these furnaces is,

$$P = \frac{C \times t}{D},$$

in which P = the working pressure, t = the thickness in inches, D = the outside diameter measured to the bottom of the corrugations and C = a constant.

C = 14,000 for Fox corrugations.
C = 14,000 for Purves corrugations.
C = 13,500 for Morison.
C = 8,800 for Adamson's rings.
C = 5,677 for plain flues three feet in length and between 16 and 40 inches diameter.

What is the necessary thickness of a Fox furnace 8 feet long, 40 inches in diameter, with a working pressure of 165 pounds?

$$P = \frac{C \times t}{D}, \qquad t = \frac{P\,D}{C}$$

$$t = \frac{165 \times 40}{14,000} = .47 \text{ inch.}$$

If the thickness is made $\frac{1}{2}$ inch the allowable pressure is 175 pounds, because,

$$P = \frac{C \times t}{D} = \frac{14,000 \times .5}{40} = 175.$$

According to the Board of Supervising Inspectors this formula applies only to those furnaces whose corrugations do not exceed 8 inches from center to center and the plain parts at ends is not more than 9 inches.

Methods of Connecting Furnaces to End Plates. Three forms of furnace connection are shown in Figs. 33 to 35. In Fig. 33 the furnace is flanged to meet the front. This is better than any form of angle iron but it has the defect that the pressure tends to open the joint. If this form is used the radius of flange should not be less than $1\frac{1}{2}$ inches. In Fig. 34 is shown the method of flanging the end plate inward to meet the furnace. This method gives a good appearance to the front of the boiler and allows space for manholes. Flanging the plate outward as shown in Fig. 35 is used more for small boilers. For this flanging the plates must be of good quality. Mild steel is the best material, as it can be flanged readily.

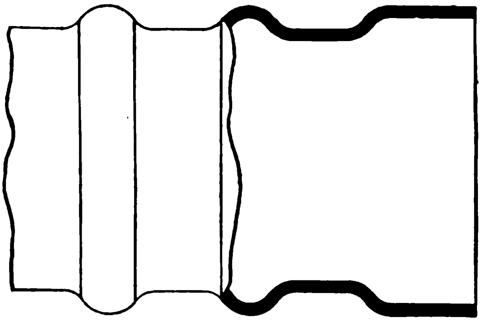
Fig. 32.

The longitudinal joints of furnaces are usually welded. In case the joints are riveted, the butt joint with double straps and single riveting should be used. Steel furnaces are almost always welded.

COMBUSTION CHAMBERS.

The Combustion Chamber is the space into which the hot gases from the furnace pass and where the hydrocarbons are burned. Its volume depends upon the size of the furnace flues.

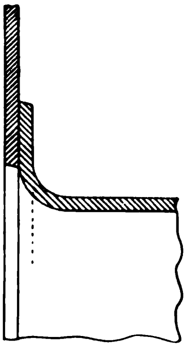
Fig. 33.

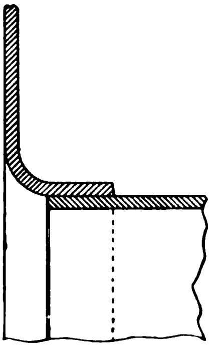
Fig. 34.

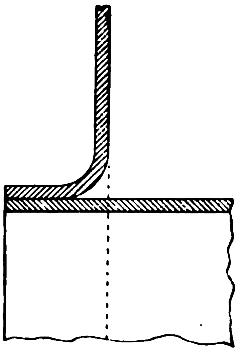
Fig. 35.

The capacity of this chamber above the grate bars is usually made about equal to the capacity of the furnace for a single ended boiler. For a double ended boiler having a combustion chamber common to opposite furnaces, the volume of the combustion chamber should equal three-fourths of the combined volumes of the two furnaces. In the single ended boiler the length of the combustion chamber is made about two-thirds of the furnace diameter.

The top plates of combustion chambers are generally flat in double ended boilers and either flat or curved in single ended. The flat tops require more staying than the curved, but they increase the volume slightly.

The side plates curve with the boiler shell as shown in Fig. 7. The front plate of the combustion chamber is the rear tube sheet; the back plate is flat and is nearly parallel to the back plate (if single ended) or arranged as shown in Fig. 6.

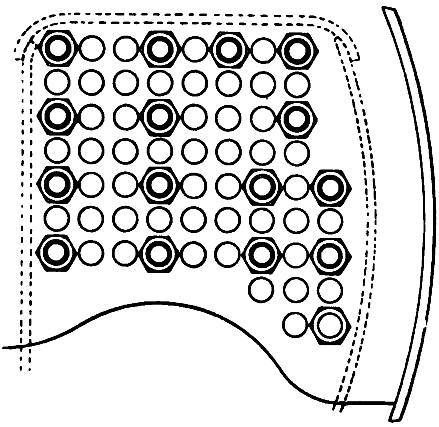

Fig. 36.

The plates of combustion chambers are from ½ inch to ¾ inch thick. The top and bottom plates are often made a little thicker to reduce the staying and to allow for wear. All joints of combustion chambers are made by riveting the flanged edges. The joints should be so arranged that no rivets or edges of plates are exposed to the direct action of flame, and also, so that there will not be a ledge formed upon which sediment may collect and cause corrosion.

TUBES.

The tubes for marine boilers are made of wrought iron or steel and are from 2¼ to 4 inches in external diameter. The length varies from 25 diameters for natural draft to about 40 diameters for forced draft. In boilers of the U. S. Navy the tubes are about 2½ inches in diameter and 6½ to 7 feet long. The thickness of the tubes depends upon the material and the diameter. The table on page 32 gives the principal dimensions of lap-welded wrought iron boiler tubes. Steel tubes can be obtained "solid drawn," that is, without any joint. The tubes are often made

LAP WELDED BOILER TUBES.

External Diameter. Inches.	Internal Diameter. Inches.	Thickness. Inches.	Internal Circumference. Inches.	External Circumference. Inches.	Internal Area. Square Inches.	External Area. Square Inches.	Length of tube per sq. ft. inside. Feet.	Length of tube per sq. ft. outside. Feet.	Weight per foot. Lbs.
1	.856	.072	2.689	3.142	.575	.785	4.460	3.819	.708
1¼	1.106	.072	3.474	3.927	.960	1.227	3.455	3.056	.900
1½	1.334	.083	4.191	4.712	1.396	1.767	2.863	2.547	1.25
1¾	1.560	.095	4.901	5.498	1.911	2.405	2.448	2.183	1.665
2	1.804	.098	5.667	6.283	2.556	3.142	2.118	1.909	1.981
2¼	2.054	.098	6.484	7.069	3.314	3.976	1.850	1.698	2.238
2½	2.283	.109	7.172	7.854	4.094	4.909	1.673	1.528	2.755
2¾	2.533	.109	7.957	8.639	5.039	5.940	1.508	1.390	3.045
3	2.783	.109	8.743	9.425	6.083	7.069	1.373	1.273	3.333
3¼	3.012	.119	9.462	10.210	7.125	8.296	1.268	1.175	3.958
3½	3.262	.119	10.248	10.995	8.357	9.621	1.171	1.091	4.272
3¾	3.512	.119	11.033	11.781	9.687	11.045	1.088	1.018	4.590
4	3.741	.130	11.753	12.566	10.992	12.566	1.023	.955	5.32
4½	4.241	.130	13.323	14.137	14.126	15.904	.901	.849	6.01
5	4.720	.140	14.818	15.708	17.497	19.635	.809	.764	7.226
6	5.699	.151	17.904	18.849	25.509	28.274	.670	.637	9.346
8	7.636	.182	23.989	25.132	45.795	50.265	.500	.478	15.109
10	9.573	.214	30.074	31.416	71.975	78.540	.399	.382	22.190
12	11.542	.229	36.260	37.699	103.749	113.097	.330	.318	28.516
16	15.458	.271	48.562	50.265	187.667	201.062	.247	.238	45.200
20	19.360	.320	60.821	62.832	294.373	314.159	.197	.190	66.765

slightly larger at the front end in order that they may be easily removed; about $\frac{1}{16}$ inch greater diameter is sufficient.

Tubes are usually expanded in the tube sheets as explained in "Construction of Boilers." The tubes are usually arranged in horizontal and vertical rows and not staggered. In the same boiler it is well to have about the same number of tubes for each furnace.

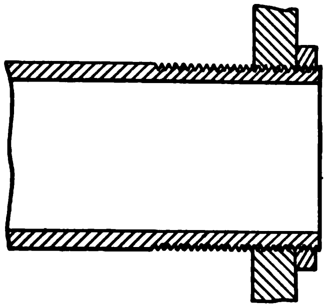

Fig. 37.

The tube sheets are usually from $\frac{9}{16}$ inch to $\frac{3}{4}$ inch thick. In large boilers with high pressure the tube sheet may be $\frac{7}{8}$ inch thick.

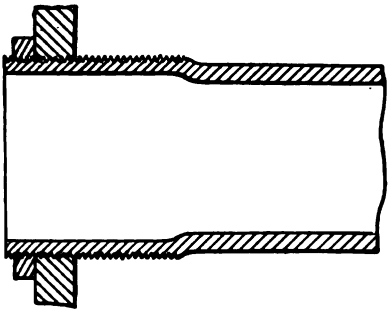

Fig. 38.

Stay Tubes. In order to prevent the tube sheets from bulging, thereby causing leaks at the tube ends, a few of the tubes (Fig. 36), are fitted as stay tubes. These tubes are made of the same external diameter as the ordinary tubes but of greater thickness. This extra thickness allows threads to be cut on the ends and rivets fitted. There are usually 14 threads per inch. Stay tubes are usually about $\frac{1}{5}$ inch thick; the threads may be formed on the tube as shown in Fig. 37, or the end may be made larger as shown in Fig. 38. Frequently the threads are cut at both ends; both tube plates are tapped and the tubes screwed in. When both ends are threaded one end must be smaller than the other so that it may be slipped through the hole. The back end is beaded over or nutted and the front end fastened with shallow nuts. Sometimes two nuts are placed on the front end; one inside and one outside of the boiler plate.

STAYS.

All plates of a boiler that are not cylindrical or hemispherical must be stayed. This is done by means of rods called stays. There are many methods of staying; the same flat surfaces of one boiler even may be stayed in different ways. The stays for each boiler are designed especially for that boiler according to the experience and judgment of the engineer.

Stay bolts. The back and side plates of the combustion chamber of the cylindrical return tube marine boiler are flat or nearly so. These plates are stayed to the sides and back of the boiler by means of short screw stay bolts which are turned down in the center. These bolts are screwed in place, calked, and then fastened by shallow nuts as shown in Fig. 39. The nuts should be of about the same thickness as the plates ; also they should be set up tight without any washers, lead, or cement. In some cases, however, a beveled washer is necessary ; this is shown in Fig. 40. Whenever these washers are used the taper should be slight.

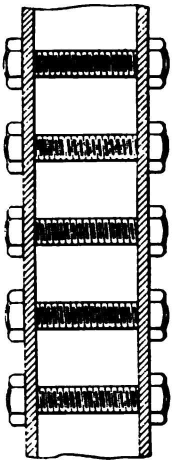

Fig. 39.

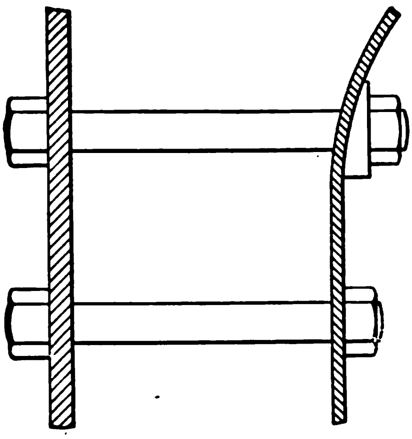

Fig. 40.

The number of stays depends upon the working pressure, thickness of plate and the pitch of the stays. They are usually arranged in horizontal and vertical rows. The short screw stays are from 1¼ to 1½ inches in diameter and are supplied with a fine thread. The pitch of the screw threads varies a little; a fine thread gives a large effective diameter but if the plates bulge between the stays only a few threads remain in contact with the plate. This difficulty is largely overcome by nuts.

An equation for determining the distance between the stays is,

$$a^2 = \frac{9\, t^2\, S}{2\, p}$$

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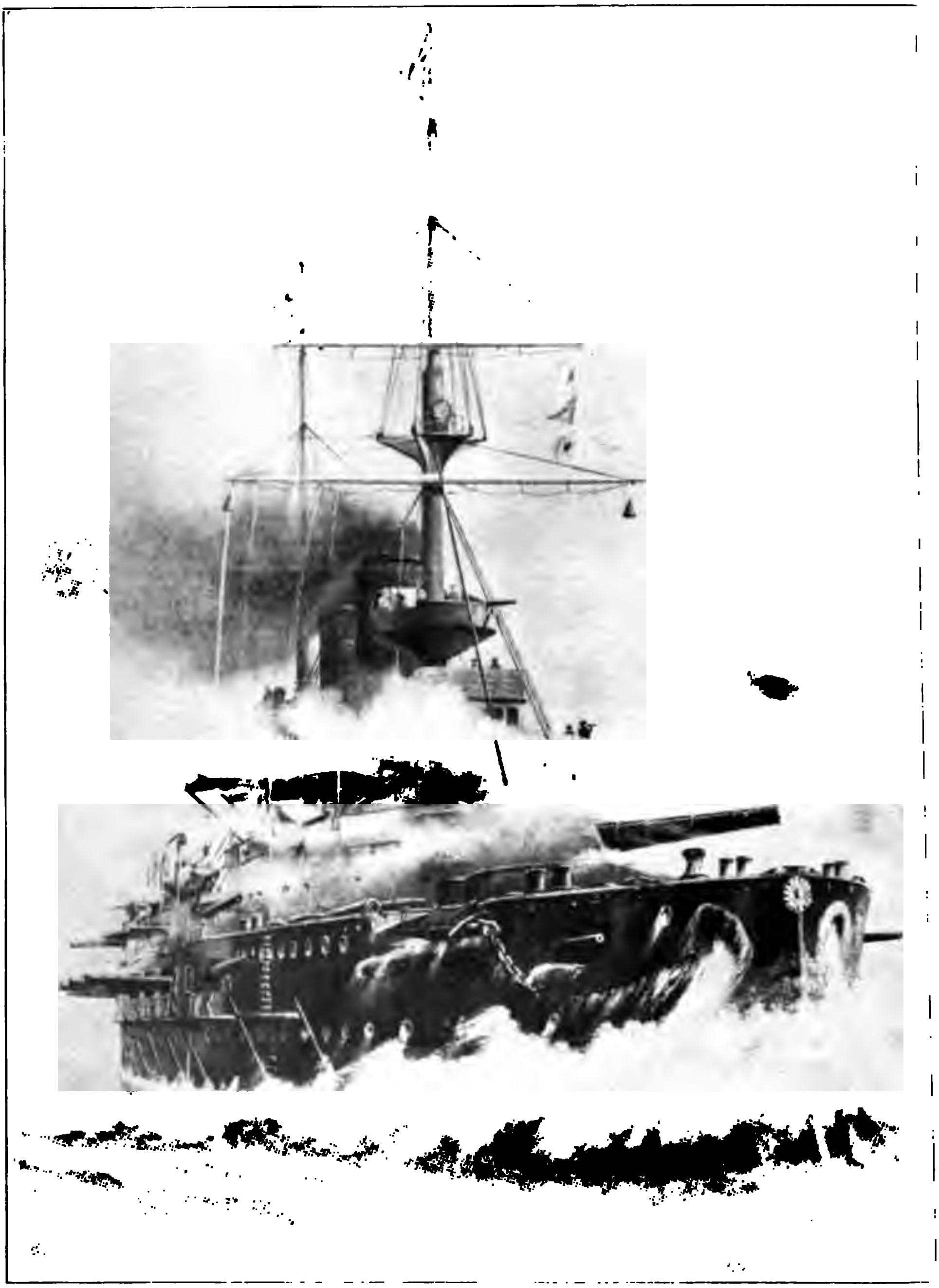

JAPANESE BATTLESHIP MIKASA.

Flagship of Admiral Togo during the blockade of Port Arthur. Built in England. Destroyed by accident explosion of magazine shortly after conclusion of hostilities, 1905.
Displacement, 15,200 tons; speed, 18.6 knots.

in which a = distance between stays, t = thickness of the plate, S = stress in the plate, and p = working pressure.

Suppose the plates are $\frac{5}{8}$ inch thick, the working pressure is 160 pounds and the stress is 5,500 pounds, then,

$$a^2 = \frac{9 \times (\frac{5}{8})^2 \times 5{,}500}{2 \times 160}$$
$$= 60.42 \text{ sq. in.}$$
$$a = 7.77 \text{ inches.}$$

The Rules of the Board of Supervising Inspectors of Steam Vessels give the following. For plates $\frac{7}{16}$ inch and under to find the working pressure, multiply 112 by the square of the thickness in sixteenths and divide the product by square of the pitch of the stays.

Example. Plates $\frac{7}{16}$ inch thick and the stays 6 inches apart; what is the working pressure?

$$\frac{112 \times 49}{36} = 152.44 \text{ pounds.}$$

For plates over $\frac{7}{16}$ inch thick the constant is 120 instead of 112.

Example. Plates $\frac{5}{8}$ or $\frac{10}{16}$ inch thick and the stays 8 inches apart; what is the working pressure?

$$\frac{120 \times 100}{64} = 187.5 \text{ pounds.}$$

If the stays have nuts on both the inside and outside of the plates, the constant is 140.

Example. Plates $\frac{9}{16}$ inch thick and the bolts 10 inches apart; what is the working pressure?

$$\frac{140 \times 81}{100} = 113.4 \text{ pounds.}$$

Through Stays. The flat ends of cylindrical boilers are stayed in many different ways. We have seen how the back plates are stayed to the combustion chamber by short screw stays; also that the tube sheets are held together by the tubes, a few of which are fastened with nuts. In the steam space are placed through stays or diagonal stays. Most marine boilers are short; therefore, the through stays are generally used. These stays are usually plain rods $1\frac{1}{4}$ to $2\frac{1}{2}$ inches in diameter. The ends are fastened to the plates by nuts and washers as shown in Figs. 41 and 42. The large washers are used to secure a greater bearing surface; they are usually riveted to the end plates.

These stays being in the steam space should be at least 14 inches apart so that a man can pass between them. The threads at the ends may be cut on the plain rod or the ends may be forged larger and the threads cut on the enlarged part. In order to reduce the number of stays the heads of the boiler may be curved as shown in Fig. 43. This form reduces the volume of the steam space but gives a stronger boiler. This construction is used in the U. S. Navy to some extent.

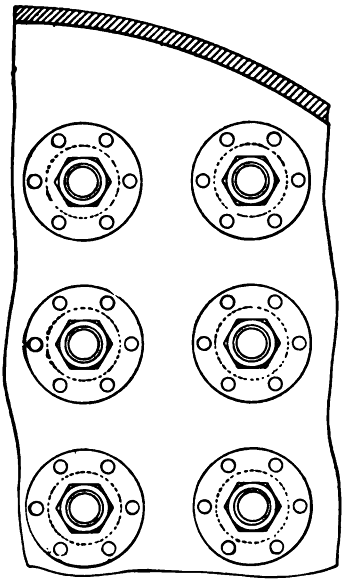

Fig. 41.

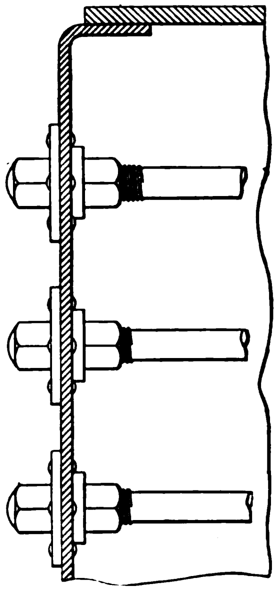

Fig. 42.

The size and number of through stays depends upon the pressure and the thickness of the plates. The spacing of the stays depends upon the size and form of the particular boiler. The diameter of the stays should be calculated to give a section sufficient to bear the load. Stays should not have a load of more than 6000 pounds per square inch if of wrought iron, and 9000 if of steel.

For long boilers the flat ends may be stayed to the shell plates by means of diagonal or gusset stays as described in " Construction of Boilers."

Girders. The tops of the combustion chambers are generally flat. To support this flat surface the girder or crown bar is used. The usual forms have been discussed in "Construction of Boilers."

The English Board of Trade give the following formula for calculating the working pressure,

$$\frac{C \times d^2 \times T}{(W - P) D \times L} = \text{working pressure}$$

W = width of combustion chamber in inches.
P = pitch of bolts in girder.
D = distance between girders from center to center in inches.
L = length of girder in feet.
T = thickness of girder in inches.
N = number of supporting bolts.
d = depth of girder in inches.

$$C = \frac{N \times 1000}{N + 1}, \text{ if the number of bolts is odd.}$$

$$C = \frac{(N + 1) 1000}{N + 2}, \text{ if the number of bolts is even.}$$

DIMENSIONS OF A BOILER.

The **diameter** of a return tube cylindrical boiler is largely dependent upon the necessary grate area. The diameter of a furnace is limited on account of the danger of collapsing ; the length of the grate is also limited. Hence to increase the grate area there must be more furnaces. If another furnace is added the diameter of the boiler must be increased.

In order to fix the **area of the grate** the amount of steam required per hour should be known, at least approximately. One pound of good coal will evaporate 10 pounds of water in an ordinary marine boiler. If the coal is of ordinary quality only about 8 pounds of water can be evaporated per pound per hour. The amount of coal burned per square foot of grate (natural draft) is about 20 pounds ; with good stoking 25 pounds.

Hence, for good conditions (natural draft) the amount of water evaporated per square foot of grate is 10 × 25 = 250 pounds. From this the size of the grate can be calculated. Thus, if the engine uses 15,000 pounds of steam per hour and the evaporation is 250 pounds per square foot, the total grate area must be $\frac{15,000}{250} = 60$ square feet. Then if the furnaces are 40 inches in diameter and the grate bars are 6 feet long, the number of furnaces would be, $\frac{60}{6 \times 3\frac{1}{3}} = 3$.

If forced draft is used the number of pounds of coal burned per square foot per hour may be greatly increased; the amount being from 25 to 75 pounds. This increases the evaporation per square foot and consequently the grate area can be reduced.

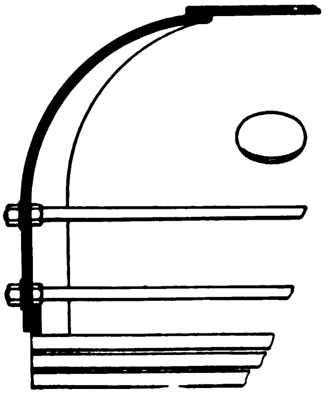

Fig. 43.

Heating Surface. All surfaces of the boiler, which transmit heat to the water, are heating surfaces. In calculating the total heating surface of a marine boiler, the sum of the following parts is taken.

Furnace. The surface of the upper half of the furnace; or the part above the level of the grate bars.

Combustion Chamber. The part above the level of the bridges, including the actual area of the back tube plate.

Tubes. The external surface of the tubes measured between the tube sheets.

The front tube sheet is not considered heating surface.

The total heating surface of marine boilers is from 25 to 38 times the grate area. For U. S. battleships and cruisers it is from 30 to 35.

The area of the tubes is about .85 of the total heating surface.

Area through Tubes. The combined internal area of the tubes, or the area through which the hot gases and smoke pass to the uptake, is generally from $\frac{1}{7}$ to $\frac{1}{5}$ the area of the grate. Too small an area checks the draft, especially if the tubes have become choked with soot and ashes. Too large an area permits a slow velocity of the gases, which, although it gives time for heat to pass to the water, also allows soot and dust to form in the tubes and reduce evaporative efficiency.

Steam Space. The distance from the top row of tubes to the top of the shell is generally from .25 to .30 of the boiler diameter. If the tubes are too high the steam space will be contracted and the water surface reduced. Priming may be caused by too small a water surface as well as by a contracted steam space.

The necessary volume of the steam space depends upon the amount of steam used in a given time. If the steam space is small the admission of steam to the cylinders is likely to cause a drop of pressure in the boiler, which in turn causes a rapid evaporation at the time. Excessive ebullition causes priming. A slow speed engine, which takes steam at intervals, requires a larger steam space in the boiler than does a high speed screw engine which uses steam at such frequent intervals that the flow is nearly constant.

The volume of the steam space varies with different conditions. For fast running screw engines there should be about ½ cubic foot per I. H. P. of the engine. This space may be made much less if forced draft is used. Volume of steam per stroke and not weight determines the size of the steam space, hence the higher the pressure the less the steam space.

Water Spaces. The spaces between the various parts of the boiler should be sufficiently large to allow good circulation. The spaces between nests of tubes should be 10 or 12 inches in order that a man may enter and clean the tubes. Between the furnaces and between the furnaces and shell the space should not be less than 6 inches. The space between the back plates of the combustion chamber and the shell, or the back plates of the combustion chambers if double ended, should taper from about 6 inches at the bottom to about 9 or 12 inches at the top. The larger space at the top is for the greater volume of the heated water and steam. If spaces are less than 6 inches they are hard to clean and the circulation is likely to be poor.

Size of Boiler. Now that the area of tubes, size of grate, area of heating surface, volume of combustion chamber and steam space are known, the size of the boiler can be determined.

In general, the boiler should have $1\frac{3}{4}$ to 2 cubic feet of volume per I. H. P. for natural draft and $1\frac{1}{4}$ to $1\frac{1}{2}$ for forced draft. However, no fixed rules can be given, as each boiler is designed for the given conditions and these may vary considerably. Low pressure demands a larger boiler than high pressure. Boilers for ships in merchant marine and those designed for long voyages have large boilers.

Area of Uptake and Funnel. In determining the size of the funnel many conditions are considered. The funnel is often designed to suit the appearance of the ship. Some engineers prefer a small high funnel while others have a tendency to use a short funnel of large diameter. The best diameter is fixed by rules based on successful practice.

The area of the funnel is from $\frac{1}{8}$ to $\frac{1}{6}$ that of the grate. In the navy the funnels are made as small as possible for obvious reasons. The principal reasons for reducing the size of the funnel in the merchant marine are wind pressure, cooling action of wind and appearance. A funnel $\frac{1}{5}$ to $\frac{1}{6}$ the area of the grate and whose top is about 40 feet above the grate will generally give good results.

When forced draft is used the funnel may be made shorter and smaller. In the navy the top of the funnel is about 75 feet above the grate. Funnels are usually circular in section but sometimes are made oval. They are made of plate iron with lap or single butt joints, the butt strap being on the inside. The plates should be thicker at the bottom than at the top. For naval vessels the funnel plates are usually of steel and are made as light as possible.

Manholes. Manholes and handholes are very similar; the chief difference being that of size. The uses and general construction has been described in "Construction of Boilers." There should be one or more manholes of a size at least 12 × 15 inches in every marine boiler. There is usually one in the shell, in the steam space; two or more are usually placed in the end of a single ended boiler and in each end if the boiler is double ended. The hole cut in the plate should be strengthened by a plate or ring to compensate for the metal cut out. Another way is to flange the plate inward; the flange stiffening the plate and forming a good face for the door joints. The doors are placed inside the boiler and are held in place by crossbars called "dogs." Sometimes a large manhole cover is fitted externally and held in place by bolts.

The Rules of the Board of Supervising Inspectors state that all manholes for the shells of boilers over 40 inches in diameter shall have an opening of at least 11 × 15 inches in the clear. Also: Manhole openings, flanged, invariably should have a depth and thickness of flange to furnish as many cubic inches of material as was removed from the plate to form the opening.

In order to show the principal dimensions of a boiler, and the proportions of the various parts, the following description and table is given. It states in detail the dimensions of one of the main boilers of the U. S. battleship "Massachusetts," which is one of the most recent and most powerful battleships of the Navy.

There are four double ended main boilers and two single ended auxiliary boilers. All the boilers are of steel and of the horizontal fire-tube type. Each main boiler has eight furnaces; four in each end. The auxiliary boilers have four furnaces in each. The shell of the main boiler is made of three courses of three plates each; the rivets being $1\frac{1}{4}$ inches in diameter. The longitudinal joints are treble riveted with double butt straps. The circumferential seams are double riveted lap joints. The joints of the combustion chambers are single riveted. The heads of the main boilers are flat but those of the auxiliary boilers have curved end plates. The radius of the curve is 2 feet $2\frac{1}{2}$ inches at the front end and 2 feet $1\frac{39}{64}$ inches at the back end. The furnaces are fitted with Cone's patent shaking grate bars.

The circulation, while starting the fires, is obtained by means of Weir's hydrokineters. Each boiler has 4 safety valves, $3\frac{1}{2}$ inches in diameter, on one base.

All the tubes are of steel. There are two main smoke pipes and two auxiliary smoke pipes, the latter within the former. The mechanical draft is obtained by means of Sturtevant blowers and the closed fire-room system.

BOILERS OF THE U. S. S. "MASSACHUSETTS."

FOUR DOUBLE ENDED CYLINDRICAL BOILERS.

DETAILS OF ONE BOILER.

Working pressure	160 pounds
Length	18 feet
Diameter	15 feet
Thickness of shell	$1\frac{19}{64}$ inches
Thickness of heads, top	1 inch
Thickness of heads, bottom	$\frac{3}{4}$ inch
Thickness of tube sheets	$\frac{5}{8}$ inch

FURNACES.

Number in each boiler	8
Thickness	$\frac{1}{2}$ inch
Greatest external diameter	3 feet 4 inches
Least internal diameter	3 feet
Length of grate	5 feet 9 inches

COMBUSTION CHAMBERS.

Number	4
Thickness of plate	$\frac{9}{16}$ inch
Width at top	2 feet $5\frac{3}{8}$ inches
Depth	7 feet $2\frac{5}{8}$ inches

TUBES.

Outside diameter	$2\frac{1}{2}$ inches
Length between tube sheets	6 feet $1\frac{1}{4}$ inches
Number, ordinary	676
Number, stay	248
Thickness, ordinary 12 B. W. G.	.109 inch
Thickness, stay 6 B. W. G.	.203 inch
Spaced vertically	$3\frac{1}{2}$ inches
Spaced horizontally	$3\frac{3}{4}$ inches

STAYS.

Diameter of screw stays	$1\frac{17}{64}$ inches
Number of through braces (upper)	24 of $2\frac{1}{4}$ inches diameter 3 of $2\frac{1}{2}$ inches diameter
Number of through braces (lower)	3 of $1\frac{3}{4}$ inches diameter
Number of braces around lower manhole	12 of $1\frac{3}{4}$ inches diameter
Number of braces from head to back tube sheets	20 of 2 inches diameter

HEATING SURFACE.

Tube	3647.5 square feet
Furnace	245 square feet
Combustion chambers	418 square feet
Total	4,310.5 square feet
Grate surface	138 square feet
Area through tubes	25.13 square feet
Area over bridge walls	15.56 square feet
Volume of furnace and combustion chamber above grates	559.93 cubic feet
Volume of steam space, water level 6 inches above top tubes	737.41 cubic feet
Water surface, water level 6 inches above top tubes	239.22 square feet

SMOKE PIPES. (TWO)

Diameter	7 feet
Total area	68.42 square feet
Height above lowest grate	70 feet

STOP VALVES.

Diameter of main stop valve	9 inches
Diameter of auxiliary stop valve	5 inches

TOTALS, FOUR BOILERS.

HEATING SURFACE.

Tubes	14,590 square feet
Furnaces	980 square feet
Combustion chambers	1,672 square feet
Total	17,242 square feet
Grate surface	552 square feet
Area through tubes	100.52 square feet
Area over bridge walls	62.24 square feet
Volume of furnaces and combustion chambers	2,239.72 cubic feet

RATIOS.

Tube H. S. to G. S.	26.43 : 1
Furnace H. S. to G. S.	1.78 : 1
Combustion chamber H. S. to G. S.	3.01 : 1
Total H. S. to total G. S.	31.24 : 1
Area through tubes to G. S.	.18 : 1
Steam room per square foot of grate	5.34 cubic feet

FURNACE DOORS.

The furnace doors for a marine boiler must be as simple as possible. They are often made of cast iron but wrought iron is better on account of the rough usage to which they are subjected.

Because of the rolling of the ship, there should be some device for holding the door open while stoking. Doors should be as small as possible so that the amount of cold air admitted while stoking and cleaning will be small. However, it must be large enough to stoke and clean the fires easily. When the furnaces are large two doors are advantageous because the amount of opening for stoking and cleaning is reduced and the sides of the grate more easily attended to. Doors should have a grid or damper for admitting air to the top of the fire.

A door made of a single plate is likely to get very hot, warp and even crack. In order to protect the door from the heat an inside plate or screen is bolted to the door. This plate is perforated with many small holes through which air passes. As the air circulates between the two plates, the door plate is kept comparatively cool; the screen may be replaced when burnt. All latches and contrivances for keeping the doors open should be very simple and strong and capable of being worked easily because the stoker's chief tool is the shovel.

Fire door frames are also injured by the intense heat and should be protected with a screen or fire brick.

GRATE BARS.

Although there are many patent grate bars and an almost innumerable number of rocking grates, most engineers have found by experience that the plain ordinary grate bars are the best. The breadth at the top is about 1 inch; the air spaces between the bars are ½ to ¾ inch at the top; the bars taper about 1 to 1½ inch per foot of depth. This makes the space at the bottom somewhat greater than at the top so that coal and clinkers will not be wedged into the space. When wrought iron or steel bars are used the spaces may be made less. The spaces are also less for forced draft.

The length of the grate is about 1½ times the diameter of the furnace. Thus for a furnace 3 feet in diameter, the grate would be $4\frac{1}{2}$ feet long. This length is, however, often exceeded. The grate bars are usually $2\frac{1}{2}$ to 4 feet long. If cast iron bars are used, they may be made about 5 feet long.

The fire bars are usually made in two lengths ; this facilitates making and handling and also provides for expansion. The grate, however, is more efficient when the bars are in one length as the cross bearer is avoided, which causes a better flow of air and also allows the fireman to "prick" the fire more effectively.

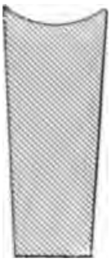

Fig. 44.

The grate should slope about 1 inch per foot. If the grates are very long the slope may be $1\frac{1}{2}$ inches per foot in order that the back end may be stoked more easily and the passage for the escape of the hot gases will be larger.

The bridge at the back end of the grate should be of such a height that the area of the passage is $\frac{1}{6}$ to $\frac{1}{8}$ of the grate surface.

Grate bars are likely to become very hot and burn at the tops. The burning is increased if the bars are irregular at the tops and the corners burned off. In case the air passages are blocked, either by warping or by clinker, air cools only one side of the bar. This will cause the other side to get hotter and hotter until the bar is burned. The slag formed from impurities in the coal melts and flows down the sides of the bars; as this slag solidifies on the sides it prevents the air from cooling the bars and as the slag at the top is thin, the heat burns the bars. To reduce burning the bars are often made concave at the top (as shown in Fig. 44), so that the ashes will accumulate there and protect the bar from the intense heat.

In order to allow for longitudinal expansion one end of the grate bars should be made slanting and the other notched to prevent sliding on the cross bar.

EFFICIENCY OF THE FURNACE.

The quantity of steam depends upon the amount of coal burned on the grate. This quantity of coal in turn depends upon the draft and the area of the grate. A furnace is said to be efficient if it burns the whole of the fuel upon it with little waste and without superfluous air. In order to produce perfect combustion there must be sufficient air to supply the necessary oxygen and the heat must be great enough to cause the chemical action.

Experiment shows that there is sufficient heat in a pound of coal to evaporate about 15 pounds of water, but in marine practice only about 10 pounds of water are evaporated per pound of coal. This shows the efficiency of the boiler to be about .7.

Among the causes of this low efficiency may be mentioned the following:

Bad stoking causes loss on account of the small pieces of coal which fall through the grate bars and are lost in the ashes. If anthracite coal is used it becomes brittle when heated and if disturbed breaks up. This loss may be as much the fault of the grate bar setting as the fireman.

If the grate bars are allowed to become uncovered or the fire become very thin an **excess of air** will enter the combustion chamber. As this superfluous air must be heated and does no good the heat is therefore wasted.

When the whole of the coal is not consumed there is of course loss. If **insufficient air** is admitted above the fire, a small portion of the fuel is not consumed but passes up the funnel as smoke. Also it may be deposited on the tubes as soot or burnt in the smoke box in the base of the furnace. The reasons for this loss are poor design and carelessness on the part of the fireman.

Perhaps the chief loss is due to radiation from the boiler shell and the various openings.

SMOKE BOX.

When the products of combustion emerge from the tubes they are conducted to the uptake by means of the smoke box. This box is constructed of iron or steel plate and is made smoke tight. It is made separate from the boiler and bolted in place by studs. The bottom of the smoke box should be at least 12 inches broad measured in the direction of the length of the boiler. If too narrow the bottom is soon filled with soot and dirt thus causing the lower rows of tubes to become inefficient if not useless. The bottom plate should be two or three inches below the lower row of tubes and the side plates about the same distance from the side rows of tubes. The smoke box front slopes outward making the top of much greater area than the bottom. The breadth at the top is about twice that at the bottom and the top plates are fastened to the boiler above the top row of tubes. Above this the shape depends upon that of the uptake and funnel.

The uptake is the part between the smoke box and the funnel. It should lead to the funnel as directly as possible and with few bends or obstructions.

The thickness of the plates for uptake and smoke box is about $\frac{1}{8}$ to $\frac{3}{16}$ inch, depending upon the size of the boiler and the material used.

The doors and plates of the smoke box should be provided with screen plates to protect them from the heat; the distance between the plates is usually about 3 inches. Also the smoke box should have a back commencing just above the top row of tubes to protect the stay rod nuts.

When several boilers discharge into the same funnel, each smoke box should have a separate uptake so that the smoke from one smoke box will not enter another. In order to control the draft and even shut off one boiler or one nest of tubes a damper is placed in each uptake.

SAFETY VALVES.

The purpose of a safety valve is to automatically relieve the boiler from excessive pressure.

The principal requisites of a good safety valve for marine work are as follows :

When raised, the area for the escape of steam should be sufficient to allow steam to escape as fast as it is formed.

Its construction should be such that it will close as soon as the pressure has fallen below the load.

It should be so arranged that it can neither be tampered with nor get out of order.

Its parts should be so constructed that the valve will act efficiently and promptly.

It must be so designed and constructed that the motion of the ship will not affect it.

Weight loaded safety valves are not now used and the lever safety valves are in use in marine work only on old boilers. This type of valve does not fulfil the above conditions as well as properly constructed spring safety valves.

The necessary size of safety valves depends upon the volume of steam generated by the boiler in a given time. This volume depends upon the area of the grate, the draft, the kind of fuel, the working pressure and the heating surface. In calculating the necessary size, most of these conditions are not considered. The size also is taken as the area of the valve but the circumference should be used instead of area because for a given lift the amount of steam released is proportional to the circumference.

There are various rules for proportioning the safety valves. With given conditions the sizes obtained by using these different rules vary considerably.

The Rules of the United States Board of Supervising Inspectors state, that the lever safety valves attached to marine boilers shall have an area of not less than one square inch to two square feet of grate surface and the seats of all such safety valves shall have an angle of inclination of 45 degrees Each boiler shall have a separate safety valve. Spring loaded safety valves of the "pop" type, there is, those constructed so as to give an increased lift by the operation of steam after being raised from their seats, shall have an area of not less than one square inch to three square feet of grate surface. Except for water-tube sectional boilers carrying a steam pressure of over 175 pounds per square inch, the area of the safety valve shall be not less than one square inch to six square feet of grate surface. Two safety valves may be used if the combined areas are equal to that of one of the required size. But no spring loaded safety valve can be used in place of a lever valve unless it has been approved by the Board of Supervising Inspectors.

The English Board of Trade gives the following rule. For boilers carrying a pressure of 60 pounds per square inch the area of the safety valve should be ½ square inch to 1 square foot of grate.

For ordinary boilers,

$$\text{Diameter of safety valve} = \sqrt{\frac{\text{area of grate}}{452}}.$$

The area of grate is expressed in square inches.

Example. There are six furnaces in a double ended Scotch marine boiler. Each grate is 3 feet wide and 6 feet long. What should be the diameter of the safety valve?

Total grate area = 6 × 3 × 6 = 108 sq. ft. = 15552 sq. in.

$$\text{Diameter of safety valve} = \sqrt{\frac{15552}{452}}.$$

$$= 5.87 \text{ inches.}$$

In case two safety valves are used the combined area should be,

$$\frac{\pi d^2}{4} = \frac{3.1416 \times (5.87)^2}{4} = 27.06 \text{ sq. in.}$$

This gives $4\frac{1}{8}$ + inches as the diameter of each valve.

The French Government rule is based on the amount of heating surface and the pressure. This is evidently a much better rule than the preceding.

$$\text{Diameter of valve} = 1.23 \sqrt{\frac{\text{total heating surface}}{\text{pressure} + 9}}.$$

The heating surface is expressed in square feet. Then if in the above example the total heating surface is 30 times the grate area (which is 108 square feet), and the boiler pressure is 150 pounds, the diameter is,

$$1.23 \sqrt{\frac{3240}{159}} = 5.55 \text{ inches.}$$

The general arrangement of the common lever safety valve is shown in "Boiler Accessories."

In order to set the valve or in other words to find the pressure at which it will blow off, we must know the diameter of the valve, the weight of the valve and valve spindle, the length, weight and center of gravity of the lever and the weight of the ball at the end. The center of gravity of the lever may be found by balancing it on a knife edge.

Then to find the pressure at which the safety valve will blow off:

1. Multiply the weight of the ball in pounds by its distance in inches from the fulcrum.

2. Multiply the weight of the valve and spindle in pounds by their distance in inches from the fulcrum.

3. Multiply the weight of the lever arm in pounds by the distance of its center of gravity from the fulcrum in inches.

Then add together the three products, (1), (2), and (3).

Divide this sum by the area of the valve in square inches multiplied by its distance from the fulcrum. The result will be the pressure in pounds per square inch.

Example. Suppose a weight of 80 pounds is hung on the end of a lever which weighs 40 pounds. The center of gravity of the lever is 13 inches from the fulcrum and the ball is 38 inches from the fulcrum. The valve and spindle weigh 20 pounds and are 5 inches from the fulcrum. If the valve is 5 inches in diameter at what pressure will the safety valve blow?

$$\begin{array}{lrcr} (1) & 80 \times 38 & = & 3040 \\ (2) & 20 \times 5 & = & 100 \\ (3) & 40 \times 13 & = & 520 \\ \hline & \text{Sum} & = & 3660 \end{array}$$

The area of the valve is $\frac{3.1416 \times 5^2}{4} = 19.635$ sq. in. and is 5 inches from the fulcrum, hence

$$\frac{3660}{19.635 \times 5} = 37. + \text{ pounds.}$$

There are many spring safety valves used. The main principles of construction and operation are discussed in "Boiler Accessories."

STOP VALVE.

The main stop valve regulates the passage of steam from the boiler to the main steam pipe or engines. One is fitted to each boiler so that any boiler or all boilers may be in communication with or cut off from the engines.

This valve should be of sufficient size to pass out with little resistance all the steam the boiler is capable of making. One of the chief reasons for a drop in pressure between the boilers and engine is a small stop valve or one so constructed as to retard the flow of steam.

Latest United States first-class battleship, the New Jersey, drawn from the working plans of the Fore River Ship and Engine Company.

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The size of the valves depends upon the steam pipes. The e of the main steam pipe may be calculated as shown in "Boiler :cessories." This method takes into consideration the amount steam used by the engine.

The diameter of the steam pipes from the boiler to the main :am pipe may be found from the following formula,

$$d = \mathrm{D}\sqrt{\frac{4}{3n}}.$$

D = diameter of main steam pipe.
d = diameter of branch pipe.
n = number of boilers (two or more).

Example. The main steam pipe is 16 inches in diameter; ıat should be the diameter of the branch pipes to the three ilers?

$$d = \mathrm{D}\sqrt{\frac{4}{3n}}$$

$$d = 16\sqrt{\frac{4}{3 \times 3}}$$

$$= \frac{16 \times 2}{3} = 11 \text{ inches (nearly).}$$

To determine the size of a pipe for any boiler, the following le may be used.

$$\text{Area} = (\tfrac{1}{4} \text{ square inch per square foot of grate} + .01 \text{ square}$$

$$\text{:h per square foot of heating surface}) \times \sqrt{\frac{100}{\text{pressure}}}.$$

Example. What is the diameter of the steam pipe of a boiler rrying a pressure of 120 pounds, and having a grate surface of square feet and a heating surface of 1494 square feet?

$$\text{Area} = (\tfrac{1}{4} \times 48 + .01 \times 1494) \times \sqrt{\frac{100}{120}}.$$

$$= 24.6 \text{ square inches.}$$

The diameter would be 5⅝ inches.

The valve and seat are usually made of bronze or gun-metal, d as full pressure is on them when shut, they should be strong ough to stand it.

Stop valves for warships and for some vessels in the merchant marine, are so constructed that whenever the pressure in the boiler becomes less than that in the steam pipe the valve immediately closes. Thus if a shot penetrates the boiler or if a tube or plate gives way, steam from the other boilers would not escape through the injured one.

Such a valve, the Foster Automatic Safety Stop Valve, is shown in Fig. 45. Steam enters at A and passes through the valve H and out at B. To start the flow of steam when the valve is closed and there is no steam passing through, open the passage E by turning the small set screw. As soon as the pressure in the diaphragm chamber accumulates to a point equal to the strength of the spring, it lifts the diaphragm, raises the valve from the seats and steam flows through.

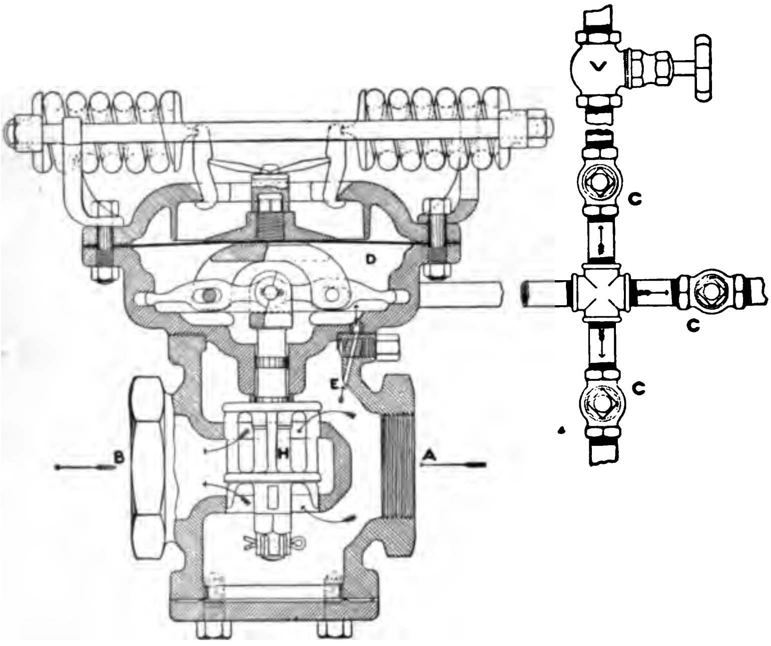

Fig. 45.

Steam continues to flow until the pressure in the chamber D falls below the power of the spring. This happens in case of accident or when the valve V is opened. The pressure in D may also be relieved through the check valves C, which lead to the boiler and to the main steam pipe.

The steam port E is about $\frac{1}{16}$ inch in diameter. The springs are adjusted for a pressure of 20 to 30 pounds below the minimum pressure carried in the boiler.

In an older form of this valve, small hand valves take the place of the check valves. This makes the valve less automatic in starting, as first one valve is opened and when steam is flowing it is closed and another opened.

Auxiliary stop valves, also automatic, are fitted to each boiler so that steam may be supplied to auxiliary machinery, independent of the main stop valve and the main steam pipe.

FEED VALVES.

As water evaporates in the boiler fresh water must be fed to take its place. In the pipe conveying the feed water from the pumps to the boiler there should be a feed valve. There should be one in the main feed pipe and a similar one in the auxiliary feed pipe. These valves should be fitted with a screw spindle from which it can be detached. The spindle is used to shut the valve when no water is required and to regulate the height of the check valve to the amount of water required. As it is independent of the spindle it acts as a self-acting non-return valve. The valve, sometimes called a check valve, should be very strong and is often made of gun-metal or bronze.

The area in square inches through the feed valve may be found from the following rule.

$$\text{Area} = \frac{\text{total heating surface}}{240}.$$

For the auxiliary feed valve,

$$\text{Area} = \frac{\text{total heating surface}}{300}.$$

BLOW-OFF VALVE.

The blow-out valve or blow-off cock is fitted at or near the bottom of the boiler in order that some of the water may be blown off as required. A pipe connects this valve with another which is placed at the bottom of the ship. By opening these two valves the boiler may be emptied of its water if there is slight steam pressure. or if empty the boiler can be filled with salt water. As sea water is now seldom used for filling boilers, this connection with the sea is useful only to blow out the water. The boiler should not be blown out except when under slight pressure, 10 or 20 pounds. This valve or cock should be strong and well made because it is subject to hard usage and neglect.

The clear area through the blow-out valve should be about 1 square inch for each ton of water in the boiler.

SCUM COCK.

The scum cock, sometimes called the brine valve, is fitted to the boiler near the water level. Scum and other impurities collect near the water line and are blown out when necessary. Sometimes a perforated pipe is connected to it; this pipe should not be lower than the lowest working level. The object of the pipe is to collect scum and floating impurities. Formerly, when salt water was used as feed water, this valve came into frequent use, for the water became very dense and a part had to be blown out and replaced with sea water. However, at the present time it is used only when the surface of the water becomes dirty.

The principal impurity in marine boilers is oil. This oil, either in patches or pellets floats on or near the surface, and hinders the free rise of steam bubbles causing the boiler to overheat. It is blown out by the scum cocks. This valve should be placed below the water level and above the heating surface so that in case of leaks or accident the water will not fall below the latter.

It is better to remove the oil from the feed by means of filters than to wait and blow it out.

WATER GAGES.

Marine boilers should be supplied with water gages and gage glasses in the same manner as stationary boilers. These fittings are described in "Boiler Accessories." They should be placed on the front end where they are easily seen. As it is very important to know the true level at all times, these fittings must be kept very clean especially if the water in the boiler contains much salt;

the deposit of salt is likely to clog the connections. The drain cock at the lower end of the gage glass should be provided with a drain pipe so that the water will not corrode the front of the boiler.

The gage glass should be placed, not on the front plate but on a stand pipe which is connected to the steam space at a point where foaming and priming will not affect it and to the water space where there is little circulation. Gage glasses are likely to indicate a wrong water level if not often blown through. There are several reasons for this : Water cools in the gage glass and in the stand pipe, is therefore of greater density and shows lower water level. An accumulation in the gage glass of distilled water (condensed steam) is lighter than the water in the boiler and causes a higher level to be indicated.

Test cocks should be fitted to the end plate. This is important as it is essential that the water level be known even if the glass breaks. Low water in a stationary boiler is dangerous but as the furnace crowns of marine boilers are so far below the water level, there is not as much danger in having low water.

STEAM AND VACUUM GAGES.

Steam gages of the Bourdon type are used to indicate the pressure in marine boilers. Their method of working and general appearance are discussed in "Boiler Accessories." Pressure gages are used on the boilers and receivers and vacuum gages on the condensers. Usually the pressure gages, vacuum gages and a clock are placed on a gage board in the engine room so that the engineer can know at all times the working conditions of the various parts of the machinery.

SALINOMETER.

Formerly it was the custom to feed boilers directly from the sea. This water, however, contains considerable solid matter, called salt, which renders it undesirable for feed water. At present the amount of sea water thus used is small.

Saline matter in sea water is measured in ounces per gallon or as a proportion in 1000 parts. Sea water contains about $\frac{1}{32}$ of its weight in solid matter. Hence sea water if analyzed shows that for every 1000 pounds there are about 32 pounds of saline matter. This amount varies in different parts of the globe. The following gives an idea of the variation. The table shows the weight of solid matter per 1000 pounds and also the ratio of solid matter per pound.

Arctic Ocean	28.5	$\frac{1}{35}$	Baltic Sea	6.6	$\frac{1}{151}$
Atlantic Ocean (equator)	40.0	$\frac{1}{25}$	British Channel	35.5	$\frac{1}{28}$
North Atlantic	45.4	$\frac{1}{22}$	Irish Sea	33.0	$\frac{1}{30}$
South Atlantic	41.6	$\frac{1}{24}$	Red Sea	43.0	$\frac{1}{23}$
Black Sea	21.0	$\frac{1}{47.6}$	Mediterranean Sea	38.0	$\frac{1}{26}$
			Dead Sea	390.5	$\frac{1}{2.6}$

Suppose this salt water is fed to a boiler. The water is evaporated and the salt left behind. As the process continues the water within the boiler becomes more and more dense because the greater the amount of saline matter present the greater the density. This increase of concentration continues until the point of saturation is reached. The point of saturation is the point at which the water has dissolved all the salt that it can and any further evaporation causes salt to be deposited.

This increase of density raises the boiling point and the deposit of salt on the heating surface, if allowed to become thick, hinders the free transmission of heat and increases the liability of burning.

For these reasons it is necessary to have some means of knowing the proportion of salt in the water of the boiler. As the density increases directly as the amount of salt an hydrometer is used. This instrument is called a salinometer when used with salt water. It is a float having a constant weight and measures the densities of liquids by the depth to which it sinks when immersed in the liquids.

The instrument is a cylindrical tube small at the upper and enlarged at the lower end. The upper end called the stem is graduated; the lower end is enlarged to give buoyancy to the instrument. This enlarged end terminates in a small globe containing shot or some heavy substance to make it float in an upright position. When it is immersed in a liquid the weight of the liquid displaced is equal to the weight of the salinometer. For a dense liquid like salt water the stem will project farther above the surface than it will in fresh water.

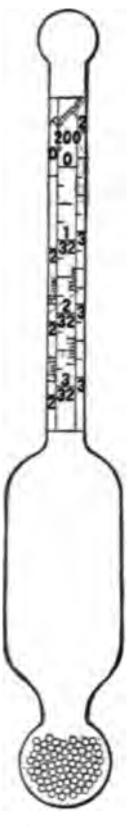

Fig. 46.

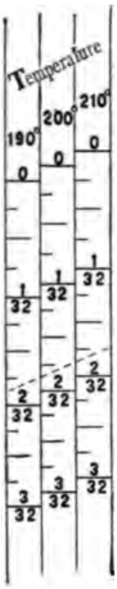

Fig. 47.

To graduate this instrument it is placed in distilled water of a known temperature and the point to which it is immersed marked zero. Then sea salt is dissolved in water at the above temperature in the proportions of one, two, and three pounds of salt to thirty-two pounds of water. The points to which the instrument sinks in these solutions are marked $\frac{1}{32}$, $\frac{2}{32}$ and $\frac{3}{32}$. These divisions are subdivided into halves and quarters. The temperature at which these graduations are made is marked in the scale. Some salinometers are graduated for three temperatures, 190°, 200° and 210° F.

Fig. 46 shows an hydrometer with the scale graduated for salt water; the scale developed and enlarged is shown in Fig. 47.

It is necessary to know the temperature within a few degrees, because for every increase of 10 degrees the instrument indicates a density of $\frac{1}{8}$ of $\frac{1}{32}$ less. Or, if the temperature is 210° and the density reading is taken on the 200° scale, the reading will be in error $\frac{1}{8}$ of one of the $\frac{1}{32}$ divisions.

The salinometer is usually made of glass. If made of copper, it should be handled carefully as any indentation alters the relation existing between the volume and weight of the instrument. As a result the scale becomes incorrect.

Hydrometers are used in connection with a salinometer-pot.

All marine boilers should be provided with a permanently attached salinometer-pot. It should be so constructed that a constant flow of water from the boiler will be maintained while testing the density. Also, it should reduce the temperature of the water to a fixed temperature below the boiling point so that ebullition and the formation of vapor will be avoided. A common form of salinometer-pot is shown in Fig. 48. Water enters the central pipe in the tall compartment and when it has risen to the height of the small holes near the top, it flows out into the compartment. It then passes to the shorter larger chamber in which is placed the hydrometer and thermometer. The water level is kept constant by means of the overflow pipe. A small hole in the cover of the tall chamber allows air and vapor to escape.

The covers of the salinometer chambers are attached to chains which prevent their being lost when the vessel rolls.

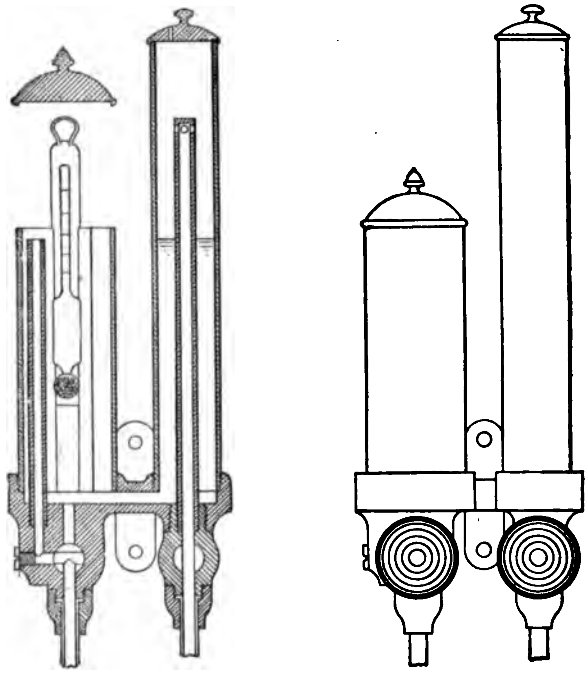

Fig. 48.

EVAPORATORS.

In all kinds of vessels, fresh water is a necessity. Those steaming on lakes and rivers can, of course, obtain fresh water with little trouble; but in the case of war ships and vessels sailing on the ocean this problem is not as easily solved. Of course a large quantity of fresh water can be carried in tanks and double bottoms but these methods are not altogether satisfactory. Water thus carried is dead weight and as it is likely to contain corrosive agents and scale forming salts it is injurious to the boiler.

The amount of make up water necessary in a large vessel is considerable. In most vessels of the present day this make up water is obtained from salt water by distillation. We know that when water is heated to form steam, the heat drives out the volatile gases and precipitates the solids. The steam thus formed is pure. Sea water is distilled in evaporators or distillers.

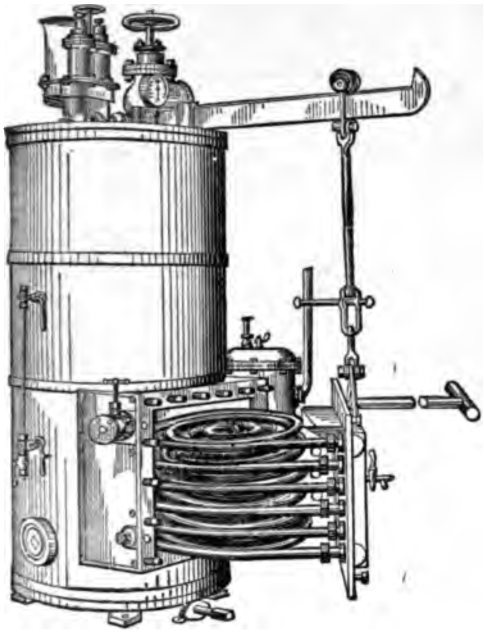
Fig. 49.

There are several evaporators having many ingenious devices but the principle upon which they all work is essentially the same. The evaporator, shown in Fig. 49, consists of a cylindrical shell similar to that of a vertical boiler and an arrangement of tubes within it. On the shell are placed such fittings as gage glass, pressure gage, salinometer, etc. Sea water is pumped into the evaporator by a donkey pump and it is then evaporated by admitting steam from the boilers or from one of the receivers to the coil of tubes. The steam thus formed from the salt water is either condensed in the auxiliary condenser or passes to the low pressure receiver. It then enters the boilers and makes up the loss from leakage, etc. The steam within the coils is partly condensed then trapped out and returned to the feed. The evaporator acts like a small boiler, the heat being supplied by steam instead of a furnace. The evaporation of sea water makes the water in the evaporator very dense and the tubes become coated with salt. When the salinometer shows the requisite density a part of the water may be blown out. The tubes are so arranged that they can easily be withdrawn from the evaporator (as shown in the figure) and cleaned. Evaporators are made both horizontal and vertical and in sizes to suit requirements.

HYDROKINETER.

We know that the water in a marine boiler below the level of the fire bars is at a much lower temperature than that above. Also we have seen that in all internally fired boilers the circulation is not good. Now, if a cylindrical marine boiler is filled with cold water and a fire is started, the water in the bottom of the boiler remains cold even after steam is formed. In order to raise the temperature of this cold water the circulation must be improved or the cold water drawn off and hot water substituted.

Some engineers adopt the above plan while others employ a small pump. Perhaps the best and most used method of improving the circulation is by means of a hydrokineter. This instrument consists of a series of nozzles one within the other. At the rear of each there is a grating through which the water passes. Steam from an auxiliary or donkey boiler is introduced into these nozzles and as it issues from the small one it causes the water to flow with the steam. With this instrument the circulation is greatly improved and the temperature of the water at the bottom of the boiler is very nearly the same as that of the water above. This plan allows steam to be raised in a much shorter time and causes the life of the boiler to be greatly prolonged while the cost of operating is practically nothing because the heat of the steam taken from another boiler enters the water in the main boiler.

FEED ARRANGEMENTS.

Marine boilers are fed with either fresh or salt water. When the water is salt it usually enters the boiler while cold; if fresh, it is taken from the hot well, and has a temperature of 100° to 140° or it may be fed cold as in the case of a lake or river steamer. The most common practice is to feed the boiler with hot fresh water heated by heaters, or from the hot well; the loss from leaks, blowing off of the safety valve, etc., is sometimes made up by taking salt water from the ocean and blowing off when the density in the boiler is about $\frac{3}{32}$. At the present time, however, this shortage is often made good by distilled water from evaporators or distillers.

The use of distilled water is advantageous because it contains no corrosive elements except a small amount of air. Sea water, however, not only deposits salt, which hinders the free transmission of heat, but contains compounds which corrode iron and steel.

One of the most harmful agents found in marine boilers is air. Pure water, if not in the presence of air, will not corrode iron. Air not only furnishes the oxygen necessary to promote corrosion by water but it also aids such chlorides as ammonium, sodium, potassium, barium, etc., in their corrosive action.

As it is almost impossible to feed water into a boiler without its containing some air, the feed should be introduced at some point where it may mix with the hot water and lose its air at a point where the corrosion will not be dangerous.

Water should never be admitted at or near the bottom of the boiler, because at that point the circulation is restricted and ashes and the inrush of cold air to the furnaces prevent heat from passing to the water. This causes the water to stay at the bottom of the boiler.

A better place to introduce the feed water is over the back ends of the tubes, so that it will be thoroughly mixed with hot water and the air readily flow to the steam space.

Many engineers prefer to inject the feed water in the form of spray at a point a little above or just below the surface of the water. This avoids all danger to the boiler plates. The feed is generally led through pipes which are fixed inside the boiler. By this plan the water is heated before it mixes with that in the boiler. This heating is of great importance if the feed is cold, as it tends to keep the boiler in good condition. The internal pipe should be so arranged that it always "runs full"; that is, it should never have any steam within it. If steam is present in the feed pipe, every stroke of the pump produces a concussion which damages the pipe and the boiler. This may be avoided by turning the end of the pipe upward when discharging above the water line, and downward with the end well below the water level, when discharging below the surface. The internal pipe is very likely to corrode rapidly but it is far more easily replaced than the plates or tubes of the boiler.

Marine boilers are fed by means of direct acting steam pumps;

injectors are seldom used. The pumps are usually vertical so that they will not take up too much floor space. There are many varieties of these pumps; the Worthington Admiralty pump shown in Fig. 50 may be taken as an example. It is of the vertical type and adapted to marine work either as a boiler feed pump or as a bilge or fire service pump. In construction and operation it is similar to the Worthington pump in general. It is usually duplex and capable of pumping against a pressure of 150 to 250 pounds per square inch.

LAGGING.

In addition to lagging the steam pipes, it is necessary to clothe the boiler to prevent loss by radiation which may amount to about 10 per cent. The material used should be incombustible and inorganic as well as a non-conductor of heat. Also, the clothing should be such that it will stand mechanical action; if it is brittle the dust formed by constant vibration is likely to get into the bearings of the engine.

In "Boiler Accessories" the various materials used for this purpose are described with a table showing their relative values. In addition to these there are several kinds of patent lagging which possess many advantages.

DRAFT.

The term draft is used in various ways. It usually refers to the difference in pressure between the gases when they leave the boiler and that of the external air. It is also used as meaning the difference between the air pressure under the grate and that on top of the coal. A third meaning is sometimes given to the word; it is the measure of the volume or weight of the gases passing over the fire in a given time.

The force of the draft is used in two ways. A portion of it is necessary to overcome the resistance of the grate and the fuel upon it, also the resistance of the combustion chamber, flues or tubes and uptake. It must also be sufficient to give the air the necessary velocity for direct combustion. Hence, if a thicker layer of coal is placed on the grate the intensity of the draft must be greater.

The draft must be sufficient to overcome the great resistance f the grate, fire, tubes, etc., as well as to supply the requisite olume of air for combustion.

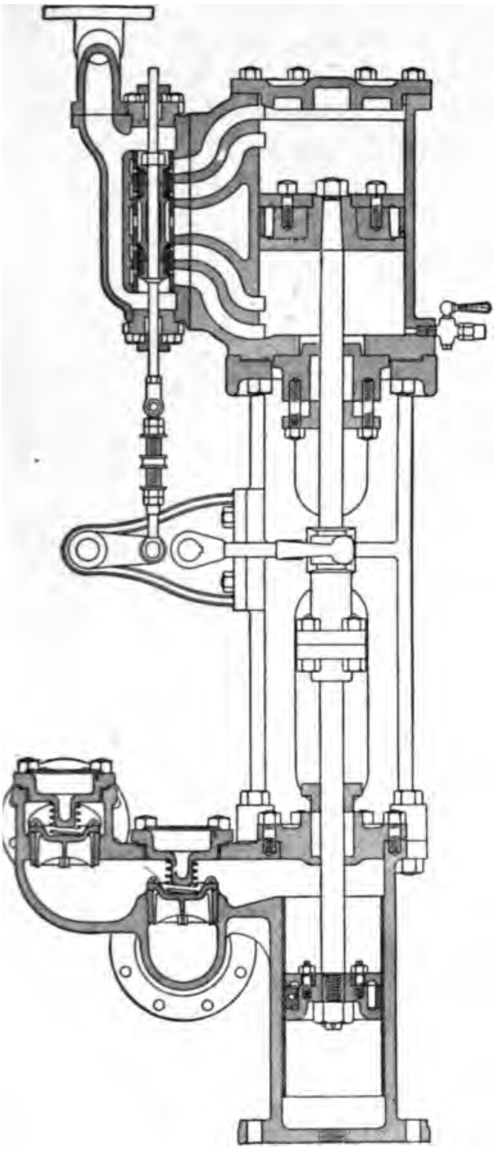

Fig. 50.

The velocity of the gases is due to a difference of pressure which, in the case of a chimney is dependent upon the temperature and the height of the chimney.

That chimneys do not always supply the necessary draft and that they must often be built very high is evident. Even changes of climate or wind often seriously impair the draft. For these reasons and on account of the impossibility of a high chimney on board a ship, some kind of artificial draft must be used.

In the locomotive, the intense draft is produced by a jet of exhaust steam. This method is not suited to marine work because the exhaust steam is condensed and used over and over again, thus reducing the amount of fresh water carried and increasing the power of the engines by the use of the condenser.

The most common method of producing mechanical draft is the fan blower. The fan for this work is what is known as the peripheral discharge type, that is, the fan consists of a number of blades extending radially from the axis. The air is drawn in axially at the center and discharged from the ends of the blades in a tangential direction. For forced draft the fan is enclosed in a case shaped so that the air will escape freely from the blades through a delivery pipe. Fig. 51 shows a Sturtevant fan used for forced draft in marine work

To design a fan of required size, the peripheral speed must be sufficient to create the desired *pressure* and the requisite *volume.*

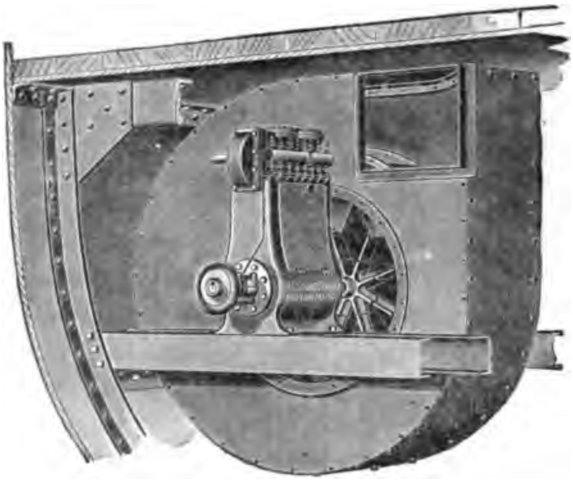

Fig. 51.

Thus, a large wheel running slowly or a small wheel running at high speed may give the desired volume and pressure. But if the wheel is too small the width may not be sufficient to permit the passage of the volume of air unless the fan is run at a speed that will make the pressure too great.

There are two methods of applying mechanical draft ; increasing the *pressure under* the grate and creating a *vacuum above* the fire. As the first method was for a long time the only one used, mechanical draft was called *forced draft.*

The usual method of applying the *induced* or *suction* draft is to use a fan exhauster in place of a chimney, that is, the fan creates the partial vacuum of the chimney; a short stack conducts the gases to the atmosphere.

With the forced draft two methods may be used, the closed ashpit and the closed fire-room.

Closed Ashpit System. This method was first applied and is the best if it can be readily adopted. In marine boilers, the air is usually forced into the ashpit which is closed to the fire-room. The pressure in the ashpit causes all leakage to be outward. Therefore, if the pressure is considerable, there is tendency to blow the ashes out of the ashpit and the flames and fuel out of the doors. In order to avoid this danger, an arrangement of double doors and dampers is used. They are often so arranged that when the doors are opened, the draft is shut off.

The great advantage of this system is that there is no leakage in the tubes at the combustion chamber end if proper care is taken.

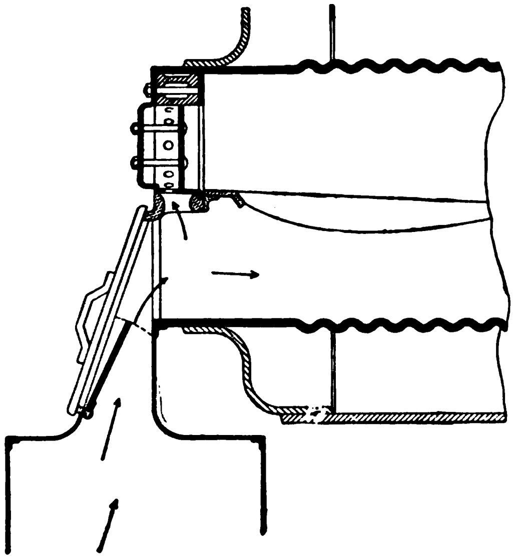

Fig. 52.

In the navy, the protective deck and the water-tight subdivisions make it difficult to use the closed ashpit system. The chief disadvantage here is the absence of ventilation. Wherever it has been used and in the merchant marine it has been on the whole, very satisfactory.

This system has another advantage ; it presents an opportunity for utilizing the heat of the waste gases.

There are several arrangements for applying forced draft by the closed ashpit system ; that known as Kafer's method is one of the best.

Kafer's Method. This method of forced draft is illustrated in Fig. 52. The ashpits are closed by means of light iron doors made air-tight by asbestos gaskets. A hinged damper, shown in the figure as partly open, regulates the supply of air to each furnace.

The air from the blower passes through the duct to the closed ashpit and from there it may enter the space under the grate or it may pass through openings in the dead plate to the space between the inner and outer door plates. The inner plate is perforated with many small holes which allow the air to enter the space over the fire. As the air pressure in the space between the inner and outer plates of the door is greater than that in the furnace no gas can escape into the fire room, the leakage being pure air which improves the ventilation slightly and keeps the fire door cool.

Closed Stoke-hold. For ordinary work and for most vessels in the merchant marine, an air-tight fire-room is impracticable. In naval vessels, however, the numerous water-tight compartments and the constructions for protection from shot and shell make air-tight fire-rooms almost a necessity. During an engagement the boiler and engine rooms must be closed and air supplied artificially Thus mechanical draft is a necessity as well as an auxiliary.

In this method air is forced into the fire-room until the pressure exceeds that in the furnaces. Then the fires are stoked in the same manner as with natural draft.

Among the advantages of the closed fire-room system may be mentioned the following. It prevents the escape of flame and smoke into the fire-room ; all the leakage being inward to the furnaces. It aids ventilation since the great quantity of air for the furnaces must pass through the fire-room.

The great objection to this method is the chilling of the interior plates of the boiler whenever the fire-doors are opened. The inrush of comparatively cold air causes local contraction of tube sheets and combustion chamber plates which soon causes leaky tubes. This system is harder for the stokers than the closed ashpit system.

Induced System. In this system a partial vacuum is formed in the furnace by means of an exhauster which is similar to a blower. The effect is very similar to that of a chimney except that the draft is steadier, more intense and far more easily regulated. When used on board ship it gives good ventilation, and is easily regulated. The early difficulty of obtaining fans that would stand a temperature of 500° or more has been overcome.

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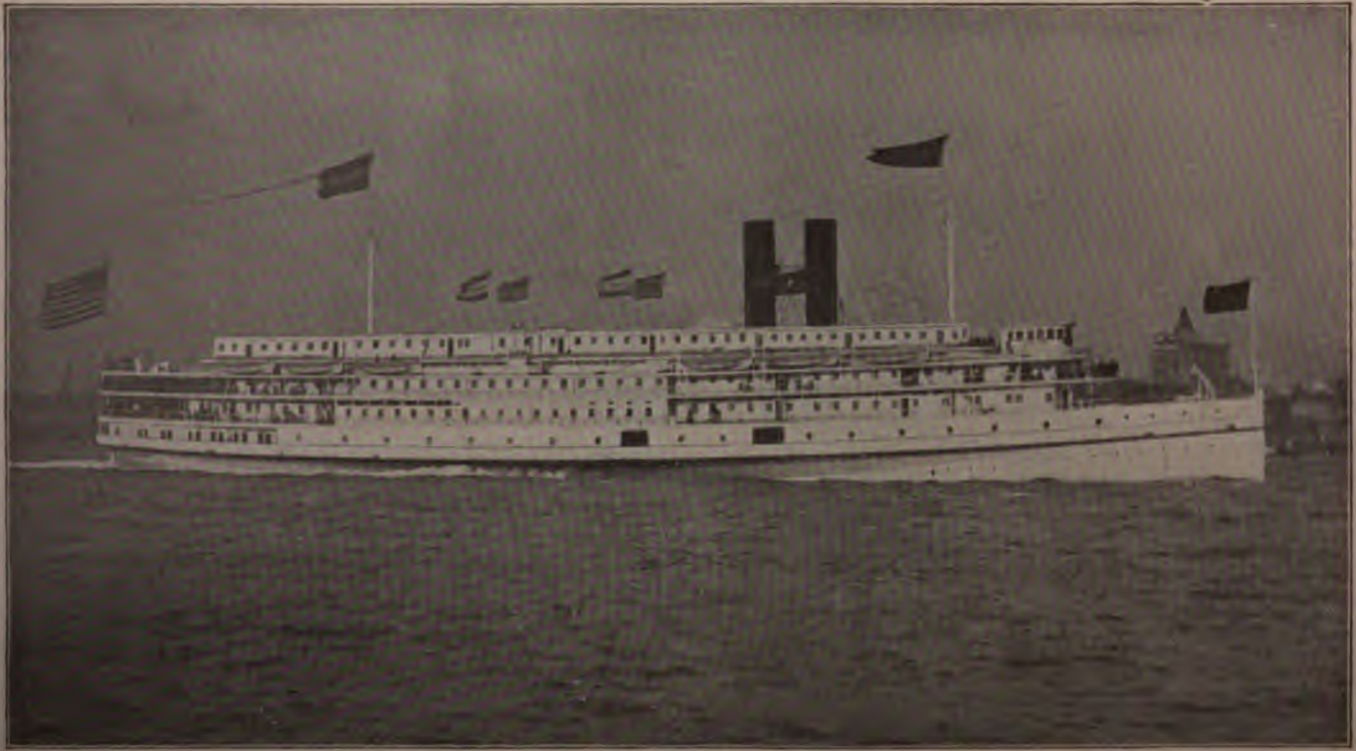

The finest type of sound steamer. From the designs of the Fore River Ship and Engine Company.

The relative efficiencies of the forced and induced systems have not been definitely determined because of the many circumstances which make the conditions unequal. However, tests seem to show that the induced system is more efficient. Probably this is due to the better distribution of air and the reduced tendency to blow holes in the bed of coal.

With this system the fan must be larger than with forced draft because the heated air occupies a much greater volume and also because the weight of air is increased by the portion of the coal which has entered into chemical combination with the air. This amount is about 5 per cent of the weight of air supplied.

Advantages of Mechanical Draft. Mechanical draft possesses many advantages for both stationary and marine work. For the navy it is a necessity because high funnels are undesirable if not impossible. Let us suppose the boilers are designed to furnish steam for the engines running at about 5,000 to 6,000 I. H. P. with chimney draft. If the enemy is sighted all possible speed is necessary and the I. H. P. must be increased to 10,000 or 16,000 in a very short time. If forced draft is not used the vessel would cruise under three or four boilers but would have in reserve four or five more. Now this extra weight is very seldom used and while unused is of course dead weight. Mechanical draft makes it possible for the fewer boilers to furnish the maximum amount of steam. This feature is especially noticeable in torpedo boats and destroyers.

In the merchant marine the forced draft system enables fewer and smaller boilers to furnish the required steam. Hence, either more passengers or a larger cargo may be carried.

With chimneys the conditions are practically fixed while with any of the three systems changes in conditions are possible.

One of the greatest advantages is the ease with which the draft may be controlled. The draft may be regulated by means of dampers in the chimney but chimney draft depends upon the state of the fire, that is, with a low fire the draft is slight. On the other hand, a fan controls the draft whether the fire is low or not. The maximum draft can be obtained almost instantly and at the time when it is most needed. Also, artificial draft may be so regulated that the steam pressure will be practically constant.

Forced draft is independent of climatic conditions; variation of wind and fog are not of any importance.

The efficiency depends upon the boiler. If with forced draft the boiler has a large ratio of heating surface to grate area, the efficiency will be greater than for a small heating surface. With chimney draft only about 20 to 25 pounds of coal can be burned per square foot of grate per hour; with forced draft 50 to 100 pounds may be burned. Thus the capacity, and perhaps the economy is increased.

Cheap fuels are much more easily employed with mechanical draft. Steamers may use a cheap inferior coal that could not possibly be burned with natural draft and ordinary grate bars.

With a chimney a high temperature is necessary to cause the requisite draft. If anything reduces this temperature the draft is impaired. With forced draft the heat in the waste gases may re-utilized in heating the feed water, or air for draft. Economizers, retarders and abstractors are successfully used with artificial draft.

The size of the boiler and hence the first cost is considerably lessened.

MECHANICAL STOKERS.

When small quantities of coal are fired at frequent intervals instead of large quantities at greater intervals an increased efficiency is the result. A mechanical stoker should then possess many advantages over hand firing. This economy, however, can be realized only when the mechanical stoker is suited to the work and properly operated.

Among the advantages may be mentioned the following: Absence of smoke, saving of labor, uniform fire, and the use of a cheaper fuel.

There are three principal types, the under feed, the inclined over feed and the chain.

In the **under feed** the coal is forced in and upward by means of a screw from beneath. The fuel is supplied along the center of the grate and as it is forced upward it falls over on the sides forming a mound. On account of the thickness of the fuel at the center the draft must be stronger there than at the sides. This is usually accomplished by means of a blower.

The **inclined over feed** stoker is a sloping grate with the highest portion at the front where the coal is fed. The grates are constructed so that they are moved at intervals so as to feed the fuel along and down the surface. This movement is usually caused by a small independent engine.

The **chain grate** is the third type. Fuel is fed at the front of the boiler to the chain grate which slowly moves toward the bridge. During this time the fuel burns undisturbed. When it reaches the bridge it is dumped as ashes. Air is supplied at various points, usually by means of some system of forced draft.

Mechanical stokers are likely to get out of order on account of the intense heat and the dirt. In order to get good results, constant attention is necessary; the rate of combustion must be regulated to suit the evaporation. Mechanical stokers are but little used at sea, although they are adapted for inferior fuels and bituminous coal.

FUELS.

The principal fuel used in marine boilers is **coal.** In some localities, however, *wood* or *petroleum* is more abundant and therefore more extensively used. The various kinds of coal are discussed in "Boiler Accessories." The kind used depends largely on the locality and choice of the owners. Bituminous coal is perhaps the most used on board ship chiefly on account of its cheapness. If the coal is in large lumps the thickness of the bed may be considerable. For very fine coal a thickness of three or four inches is most economical; a fire having such a thin bed of coal must be watched carefully and stoked almost continuously.

Patent fuels are made in blocks from small coal. This refuse from mines and coal yards cannot be easily transported unless mixed with tar, clay or some adhesive substance which holds the particles together. The heating value of these bricks depends upon the amount of coal in them.

The value of a fuel is determined by its chemical composition. All fuels contain carbon; almost all have some hydrogen, oxygen and small quantities of nitrogen and sulphur.

We know that heat is measured in British thermal units. The heat value of any given coal is equal to the sum of the heat units in the various elements.

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If one pound of carbon is burned it gives out about 14,500 B. T. U., and requires about 12 pounds of air to consume it, that is, to convert it into carbon dioxide gas. If, however, the air supply is too small, there is considerable loss, the carbon forming carbon monoxide giving out only about 4,400 B. T. U.

One pound of hydrogen gas requires about 36 pounds of air to consume it. Its heat of combustion is about 62,000 B. T. U.

Sulphur is present in good coal only in very small quantities and has a heat value of about 4,000 units.

Knowing the amount of carbon and hydrogen in a pound of coal we can compute its heat value as explained in "Chemistry."

The heat value of any coal can be calculated if the chemical composition is known ; or it may be found by burning a little coal in a coal calorimeter.

Although about 12 pounds of air are theoretically necessary in burning a pound of coal, practically 18 to 24 pounds are supplied in order that the air may readily reach the fuel and that the carbon may be burned to carbon dioxide.

CARE OF BOILERS.

To manage a boiler successfully, the desired amount of work should be obtained from it and at the same time the expenses should be kept as low as possible. This requires a knowledge which can be obtained only by experience. Beside this skill in management, the boiler must be well designed, the feed water good and the fuel suited to the boiler. Still another condition is that the necessary repairs be made promptly and the causes for deterioration removed.

It is essential that the engineer should know the positions of all piping, valves, cocks, etc., so well that he can find them in the shortest possible time, even in the dark.

Before getting up steam, all the valves and cocks should be carefully examined to see that they are in good working order.

Getting up Steam. The method of getting up steam depends upon the type of boiler, the time allowed and the condition of the other boilers aboard. For instance, steam can be raised much more rapidly in a water-tube boiler than in a long double ended cylindrical boiler. If an engineer has plenty of time he has a fire built in one furnace and steam raised very slowly. If steam must be raised quickly, fires are started in all the furnaces at once and some means is employed to increase the circulation ; a hydrokineter or steam from another boiler. In case steam is up in an auxiliary boiler, the fires in the others are started from those in the auxiliary boiler, and the steam from the latter may be used to pump water into the empty boiler. Where there are no auxiliary boilers, steam should be raised slowly by building a fire in the lowest furnace.

Let us suppose we are to raise steam in a cylindrical boiler which is empty. First, it is necessary to inspect the interior. If the plates, tubes, joints, braces and stays are in good condition, all openings should be closed. Before closing manholes and handholes, all tools, materials and articles used in repairs or inspection should be removed. If soiled overalls, hand-lamps, etc., are left in the boiler, they are likely to cause trouble by stopping up the outlets.

It is important to have the safety valves in good working condition. They should be tried often so that they will not become rusted to the seats. The connections to the water column should receive particular attention as they are very likely to become clogged with salt, especially the lower ones.

The main stop valve should be closed but not tightly; it should be "cracked off the seat." If the valve is closed tightly it may become jammed to the seat when steam is formed. It is left slightly open for other reasons ; it gives the main steam pipe a chance to become warm as far as the bulkhead stop valves (if these are fitted) ; it allows condensation to be drained off and, with the atmospheric valve, it allows the air in the steam space to get out of the boiler when steam is formed. If there is no outlet, the air in the steam space becomes compressed while steam is forming. This imprisoned air when compressed prevents the free formation of steam and also causes the pressure gage to indicate a pressure greater than that due to steam.

Water gages and cocks may be left open until the water reaches their levels.

Let us now assume that the boiler has been thoroughly inspected and everything is in good working order. The boiler may be filled by opening the bottom blow-off valve and the sea valve. It may be filled through the top manhole by means of a hose from the shore or by pumping fresh or distilled water from the ship's tanks. Boilers should be filled with warm water if possible.

While the water is rising in the boiler, serious leaks may be detected by placing lamps in the combustion chamber and by opening the front connection doors.

The furnaces may be charged when the water has reached the proper height. On account of the expansion of water when heated, the filling is stopped with the level a little below steaming point.

Building the Fire. If there is a fire in an auxiliary or donkey boiler, the fires in the boiler under consideration may be started by throwing some burning coal from the auxiliary into the furnace or furnaces of the main boiler. If this cannot be done, a fire is kindled in one or more furnaces of the boiler. The back of the grate is covered evenly with a thin layer of small coal; on the front of the bars some pieces of split wood are laid side by side, the front end being supported by a couple of pieces of wood placed crosswise. If hard oal is used, the whole of the grate is covered. Some kindling, shavings or oily waste is then placed at the furnace mouth below the layer of wood.

When the fire is lighted, the furnace doors are kept slightly open and the ash pit doors opened. A few shovelfuls of coal are thrown on the wood as soon as it is well started. When the coal at the front of the furnace becomes incandescent it is gently pushed back and more coal added. This operation is repeated until there is sufficient incandescent coal on the grate.

The fire is usually built in the lowest furnace so that the water at that point will become heated and cause a circulation. Some engineers consider that a better circulation is obtained by starting the fire in one of the wing furnaces.

In case of emergency the fires may be lighted as soon as the water covers the heating surfaces; but this is not good practice and should be avoided if possible. This rapid raising of steam is injurious to boilers especially if they are long. Under most circumstances three hours should be allowed for raising steam and more if possible. For a long double ended cylindrical boiler six hours is the shortest time to be allowed.

When building the fire and while steaming the attention of a good fireman is essential.

Stoking. A complete knowledge of stoking can be obtained only from experience. It is easy to throw coal on a fire even if the doors are small; but to place coal just where it ought to be placed when the doors are four feet above the floor and the ship is rolling is not an easy matter.

Certain varieties of coal, (anthracites) should not be disturbed after being placed on the fire, hence it is essential, with this coal, that the firemen should place it accurately; the fire should be sliced frequently. When the soft coal cakes, the fire must be broken up from time to time so that air can pass through the bed of coal.

The fires must be watched carefully; especially at the sides. Air has a great tendency to rush up between the plates of the furnace and the grate. Also air finds little resistance at thin places. All hollow places must be filled and the sides kept heavy or a damaging excess of air will rush with great violence into the combustion chamber. This rush of air is called back draft. To check this draft, open the furnace doors slightly and close the ash pit doors. To prevent the back draft the bed should be carried thicker and leveled frequently. If the hollows are more than filled the large amount of cold fuel will retard combustion at those places.

A good fire is slightly hollow in the center and has a nearly level appearance. Continual care is necessary. All fires connected with the same funnel must be kept equally thick or the thin ones will burn away fastest.

Coal should be placed on the fire frequently in small quantities. With forced draft, of the closed stokehold system, speed in firing is of the utmost importance; if the doors are kept open too long the inrush of cold air is both dangerous and uneconomical.

Thickness of Fire. The necessary thickness of the bed of fuel on the grate depends upon the kind, quality and size of the fuel, upon the draft and upon the frequency of firing. The thinner the fire the more rapid the rate of combustion. If the fires are kept thick, less cold air enters, as the doors are opened less frequently; but large volumes of hydrocarbons are produced which are often at such a low temperature that they pass unconsumed up the chimney and are wasted.

With ordinary chimney draft, anthracite coal of egg size may be carried 5 to 8 inches thick. With smaller coal the bed may be thinner. If less than 4 inches thick it is difficult to keep the grates well covered especially if of large area. With free burning bituminous coal and natural draft, the thickness of the bed may be 6 to 8 inches. The thickness of the bed with mechanical draft should be much greater, the thickness depending upon the intensity of the draft. Bituminous coal should be fired more frequently than anthracite on account of the hydro-carbons.

When the fires throw a uniform bright light below the grate, it indicates a clear active fire. When the ash pits are dark, either uniformly or in spots, it indicates an accumulation of ashes or clinker on the grates. In such cases the hook bar or prick bar is run through the spaces between the grate bars from beneath and the ashes removed. If it is difficult to move the hook bar, it is an indication that the fire needs "slicing." That is, the clinker is to be removed by inserting the slice bar between the fuel and the grate. The edges and corners are likely to become clogged with ashes and cinders unless cleaned frequently. When the accumulation of ashes, cinders and clinker become so great that they cannot be removed by pricking and slicing, the grate must be cleaned.

Cleaning the fire is a necessary operation although it is injurious to the combustion chamber plates and tube sheets. This is due to the entrance of cold air while the door is open and the grate bare. It should be done at regular intervals and at least once in every twelve hours.

Cleaning the Fire. Before cleaning the fire, it should be allowed to burn low so that it will not be too heavy. It should not, however, be too light, or there will not be chaff enough left to start the fire again. The steam should be up to full pressure and there should be plenty of water in the boiler so that the feed can be partially shut off. The draft should be nearly closed during cleaning.

With soft coal the fire is more easily cleaned than with hard coal. To clean the fire, the fireman shoves back the incandescent coal leaving the clinker and ashes on the front of the grate bars. The clinker is hauled out and the fire brought to the front on the clean bars. The ashes are then worked through the grate bars at the back and the clinker hauled out over the fire to the floor plates. The clean incandescent coal is then quickly spread all over the grate and covered with a thin layer of green coal.

Cleaning the fire requires skill and care as it often happens that the fire goes out because there is not enough coal with which to start up again.

Some firemen prefer to clean one side at a time. One half is allowed to burn down and the ashes and clinker removed; the clean bars are then covered with green coal which ignites from the heat of the other half. After a time the other side is cleaned by the same method.

Another plan, used with coking coal, is to draw the clinker forward with the rake or hoe a little between each firing and throw green coal on the bare spots. Clinker should be removed before it gets cold or it will be difficult to detach it from the bars.

For hard coal the cleaning is more difficult and requires practice. Fire small quantities of coal frequently until the proper depth of fire is maintained. Then the slice bar may be run between the coal and the fuel to shake the ashes out. Never disturb a hard coal fire, that is, never break it up as with a soft coal fire. With hard coal keep the fire as level as possible and fire more heavily at the sides.

Smoke Consumption. In "Boiler Accessories" the various methods of firing to consume smoke were discussed. In the marine boiler, there are usually three or four furnaces; these are fired in turn, so that the smoke may be consumed if there is a common combustion chamber, and the formation of steam may be more constant. With hard coal there is little smoke.

When soft coal is heated great volumes of volatile gases are liberated which must be burned. Soft coal is usually fired at the front of the furnace where the heat drives off the hydrocarbons which are consumed while passing over the incandescent coal. The coke is then shoved back. A new supply of fresh coal is next placed at the front of the grate. This plan allows the use of very long grates, but it has the disadvantage that all the ashes and clinker collect at the back of the grates where it is hard to remove them.

Banking the Fire. It frequently happens that the steam supply is to be temporarily diminished or perhaps stopped entirely for a short time. In such cases the fires should be banked but not hauled. Before banking a fire it should be cleaned so that there will be a clean fire when it is started again.

Banking the fire means pulling the coal together in a heap at some portion of the grate; combustion being thus retarded.

There are two kinds of banked fires, "heavy" and "light." In case it is desired to keep the steam near working pressure and be ready to start in about a half hour the fires are banked heavy. The fire is cleaned, the coal gathered together in a pile and covered with green coal until the heap covers about one-half the grate bars. When this fire is started the heap is spread over the whole grate and as there is considerable coal in the pile there will be a normal steaming fire. In this case, the bare grate bars are usually covered with ashes to keep the cold air out of the combustion chamber.

With the front of the grate covered with ashes and the fire banked heavy everything may be closed and all cold air kept out. The steam made while the fire is banked can be used by running dynamos, distillers, etc., or it may be taken care of by the auxiliary condenser.

In case the fire is to remain banked for a considerable time and the pressure is allowed to drop the fires may be banked light. That is, the amount of coal used is much less, covering only about one-third the grate or just enough to start the fire.

There is a difference in opinion as to whether the fire should be banked in front or at the back. It is more generally banked at the back.

When the engines are stopped suddenly, but the boilers are kept ready to start again shortly, the excess of steam goes to the condenser by opening the bleeder valve in the main steam pipe.

Cleaning Boilers. Soon after the fires are hauled the boilers should be cleaned. The tubes should be swept, beginning with the top row. While doing this all doors except those of the front connection should be closed, so that the dust will go up the funnel and not into the fire-room. Tube brushes should be made of material stiff enough to detach the hard scale which sometimes adheres to the tubes. They should fit the tubes snugly. Tube scrapers are usually made of strips of steel arranged spirally.

After cleaning the tubes, the soot and ashes should be removed from the smoke box and combustion chamber. Scrape the scale from the plates and sweep them off with a stiff broom. The furnaces. ashpits and grate and bearing bars should then be cleaned of all soot, ashes, and scale.

All fittings, such as check valves, water glass, safety-valve, salinometer-pot, etc., should be kept clean and the connections clear.

The scale should be detached as soon as the boiler is cool enough to enter, because usually it can be detached more easily when damp. If the scale is very thin it should not be removed as it protects the iron or steel from corrosion. As it grows thicker, it prevents the transmission of heat, causes the boiler to have a lower efficiency, and is likely to cause overheating.

The methods of removing scale are numerous; those which are likely to damage the boiler should never be followed. It is much better to prevent the formation of scale than to be obliged to remove it after having become thick and hard.

After the scale has been removed, all the mud and rust should be scraped from the shell, the loose scale knocked from the stays and the boiler washed out. A strong stream of water from a force pump will often clean portions of the boiler which are inaccessible. After washing the boiler, the drying out may be hastened by placing trays of burning charcoal in the furnaces.

It is very important that the boiler be kept free from all fatty acids and oils. If the boiler is not cleaned frequently, oil will lodge on the stays, tubes, furnace crowns, tops of combustion chambers and on the shell. Oil is dangerous as it causes overheating.

Repairs. All boilers, no matter how well designed, constructed and managed need repairs from time to time. If the repairs are not made promptly and with the best materials and workmanship, the entire boiler will need to be replaced. The repairs needed are of great variety and the methods of procedure for similar cases differ greatly.

Replacing Fire Bars. In case the whole grate or a large number of fire bars drop into the ashpit or are badly burned the whole grate must be replaced after the furnace has been cleared out. But if only one or two bars have dropped out they may be replaced without drawing the fire. Some firemen are skillful enough to throw them in place, but a better plan, especially for those at the back of the grate, is to fasten the grate bar to the slicer with yarn and place it in position; the yarn soon burns away and the slicer can be withdrawn.

Seams and Rivets. All leaky seams and rivets should be calked while the boiler is empty; if a rivet continues to leak after calking, it should be cut out and a new rivet put in. The same applies to rivets which have, through corrosion or wear, become so small that their holding power is greatly impaired. Sometimes bolts are used in place of rivets when the boiler is so old that the jar caused by riveting is likely to cause new leaks. When bolts are used they may be made tight by washers or by means of lamp wicking mixed or coated with white or red lead.

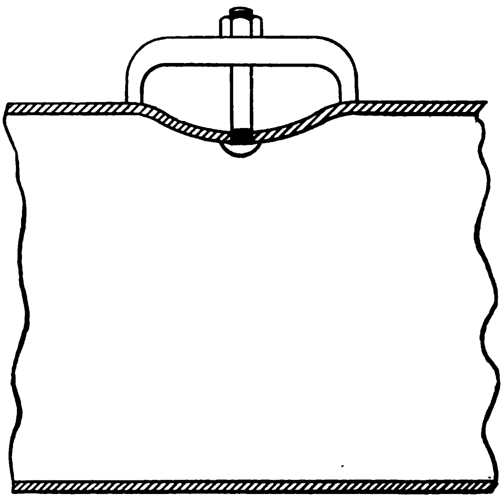


Fig. 53.

Furnaces that have come down slightly may be repaired by means of dogs that are similar to the crown bars on the tops of combustion chambers. The furnace plate is tapped at the center of the bulge and a dog placed lengthwise along the top as shown in Fig. 53. Sometimes it is necessary to place the dog circumferentially; but when so placed it has a greater tendency to slip. When the furnace comes down nearly the whole length it is held up by a series of dogs or by placing several hoops of T iron around it. Corrugated furnaces very seldom come down.

A furnace that has come down slightly may be restored to its original shape. The distorted portion is heated to a dull red and then forced to the original shape by means of blocks of wood, a screw jack and a piece of iron of the shape of the furnace. If this iron is heated it should be kept in place until both the furnace and the iron are cold; this process anneals the furnace plate. In case of collapse the entire furnace must be taken out and replaced. This is not a difficult job if the end plate and the combustion chamber plates are flanged to the furnace.

Circumferential Seams often need slight repairs on account of leaks. These repairs should be made as soon as possible as leaks rapidly increase. They are easily discovered because of the lumps of salt that collect at those places. If the boiler is lagged, soft spots in the lagging indicate leaks; if the leaks are not looked after promptly they will cause the shell to become weak. Usually these seams can be made tight by calking; but when the leak is too great for this method it is stopped by bolting a light iron cover plate over the seam as shown in Fig. 54. The space between the boiler and the cover is often filled with cement.

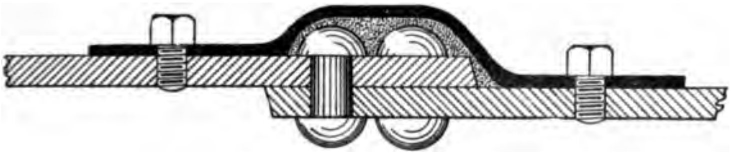


Fig. 54.

Shell Plates are patched by a **soft** patch or by a **hard** patch. A soft patch is made by securing a piece of plate over the defective portion of the boiler shell by means of patch bolts or studs. The joint is made tight by a mixture of white lead, oil, dry red lead and iron borings or filings. Soft patches must always be placed on the *inside* so that the action that caused the weakness in the original plate may come on the patch; also so that the pressure will not have a tendency to blow off the patch. A blistered plate in the furnace should be patched on the *outside*.

Soft patches are used when the boiler is old and weak; they should never be applied to a surface in contact with fire or hot gases except as a temporary expedient to stop a bad leak. A hard patch is one that is formed by riveting, or fastening by patch bolts, a piece of plate to the shell and making the joint tight by calking. The defective part of the plate should be cut away and the patch made large enough to rivet and calk. Hard patches should always be placed on the outside directly over the defective part and should be made of plate of about the same quality and thickness as the boiler shell.

When a patch is to cover a curved or uneven surface, a template should be made by hammering a piece of sheet lead into place. The piece for the patch can then be heated after drilling and made of the required shape.

A short crack can be stopped by drilling at each end and several intermediate points; these holes are countersunk and rivets placed in them. The rivet heads should be well spread by hammering. For a long crack, the plate should be cut away and a hard patch put on.

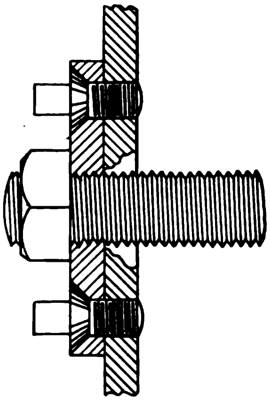


Fig. 55.

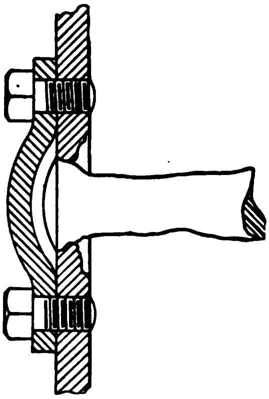


Fig. 56.

Screw Stays are often replaced both on account of the wasting of the stay and because of the wasting and bulging of the plates forming the water-leg. If the plates are thin the stays are likely to leak, especially if riveted over. Instead of renewing the stay bolt and placing a patch on the plate as shown in Fig. 55, the stay is sometimes left in place and a patch put on as shown in Fig. 56. The latter method should never be employed.

When the plates remain uninjured and the stay has wasted, a larger stay may be inserted.

Tubes often leak at the ends; if the leaks are due to the tubes they may be plugged temporarily by driving a pine wood plug into the end. These plugs should fit snugly and have a slight taper. When the leak is in the tube somewhere between the end plate and the back tube sheet it is stopped by driving a plug into the tube until the plug covers the crack. The plug will swell and salt up in a few minutes so that the leak will be tightly stopped. If the tube plate bulges, more of the ordinary tubes should be used as stay tubes or rods may be used in place of some of the tubes.

When the water-legs and bottoms of old boilers are badly worn out and cannot be made tight by calking and patching, they may be filled with cement. The cement is made thin and run in through the manholes. The surface of the cement filling should not be as high as the fire bars and the extremities of the feed and blow pipes must be kept clear.

WATER TUBE BOILERS.

For many years the cylindrical boiler has been almost the only type used in marine work. It has for that reason attained a high state of perfection. At various times engineers have tried to introduce water-tube boilers in place of the cylindrical, but on account of poor design, faulty construction or bad management the experiments have not been entirely successful. At the present time, however, an increase of speed is demanded, and as a consequence higher pressures and lighter machinery are necessary. With this increase of pressure comes increase of weight, cost and damage in case of explosion. Engineers see that the cylindrical boiler must give way to a steam generator which is lighter, stronger and safer.

A water-tube boiler, if well designed and well constructed, seems to fulfill the requirements. Although the cylindrical boiler is serviceable, efficient, and can be made to stand any reasonable pressure, yet the water-tube boiler possesses many advantages over it. When the same care and skill have been used to perfect the water-tube boiler that have been used on the cylindrical, it ought to be as efficient and reliable.

The principal objections to the cylindrical boiler are the great weight, thick plates, difficulty of moving in and out of the vessel and the small furnace space. This last disadvantage has already been discussed. Also, when the boiler is under forced draft, the time allowed for the products of combustion to give up their heat is short.

Among the advantages of this boiler may be mentioned economy, and steadiness in supplying dry steam. It is also far better suited for salt water than is the water-tube boiler but this is not a great advantage at the present time.

Water-tube boilers are built in a great variety of designs. They may be divided into different classes, as straight tube and curved tube; or the drowned tube (that is, those having the upper ends submerged) and those having the upper ends opening into the steam space. Also, there is another division; those having a steam drum and those having none.

For convenience let us divide them into two classes, straight and curved tube. In the first class we may place among others, the Almy, Belleville, Babcock and Wilcox, Heine, Yarrow, D'Allest and Niclausse. A few of those having curved tubes are the Thornycroft, Normand, Mosher and Ward.

The straight tube boilers are easy to clean but are not as flexible and therefore steam cannot be raised in them as quickly.

The various water-tube boilers differ in detail but in the main they are similar. Of those used in marine work, the Almy, Belleville, Babcock and Wilcox, Yarrow, Thornycroft and Heine are described in "Types of Boilers." Some are better than others for certain conditions and as to what boiler is the best is a matter of opinion. Among the conditions which it is desirable to satisfy are the following:

1. Lightness of structure as compared with the cylindrical boiler.
2. Simplicity of form and construction.
3. Rapidity of raising steam.
4. Small quantity of water contained.
5. Great strength in proportion to the working pressure.
6. Capability of furnishing dry steam at high pressure.

The **grate area** is determined in a similar manner to that used in designing cylindrical boilers; but for most types the area must be greater so that the heat may be distributed evenly over the surface of the tubes. It is not well to have the heat too intense near any of the tubes. The construction of most water-tube boilers allows plenty of space above the fire both for complete combustion and for the distribution of heat.

The **tubes** should be made of solid drawn steel of the best quality. Copper is not a good material on account of its weakness at high temperatures. They are from 1¼ to 3 inches in diameter except in small light boilers where they are about 1 inch.

The **circulating tubes** or down comers are usually 3 to 6 inches in diameter. They should not be exposed to heat unless the flow is constant.

The **stays** in these boilers are not as numerous as in the cylindrical. The tubes, when in good condition, may be depended upon to hold the parts together, but in case the boiler is cooled suddenly they become unreliable. If the tubes are straight some of them may be fitted as stay tubes.

The size of the **steam drum** depends upon the amount of steam generated by the boiler. In order to make it as small and as light as possible, the boilers are sometimes worked at high pressure and the pressure maintained constant at the engine by means of a reducing valve.

The water-tube boilers having the upper ends of the tubes opening into the steam space have dash plates and internal steam pipes which separate the water and steam.

The various water-tube boilers have the following advantages over the cylindrical boiler:

1. Lighter (weight usually about ½ that of the cylindrical).
2. First cost less on account of less material used.
3. Less danger of damage in case of explosion.
4. Large grate area and larger volume for combustion.
5. Greater rapidity in raising steam.
6. More easily placed aboard or removed.
7. Can be forced harder.

The last three conditions are of great importance in the navy. As to the relative economy there is much difference of opinion as the conditions vary considerably. In general the economy is about equal in both types.

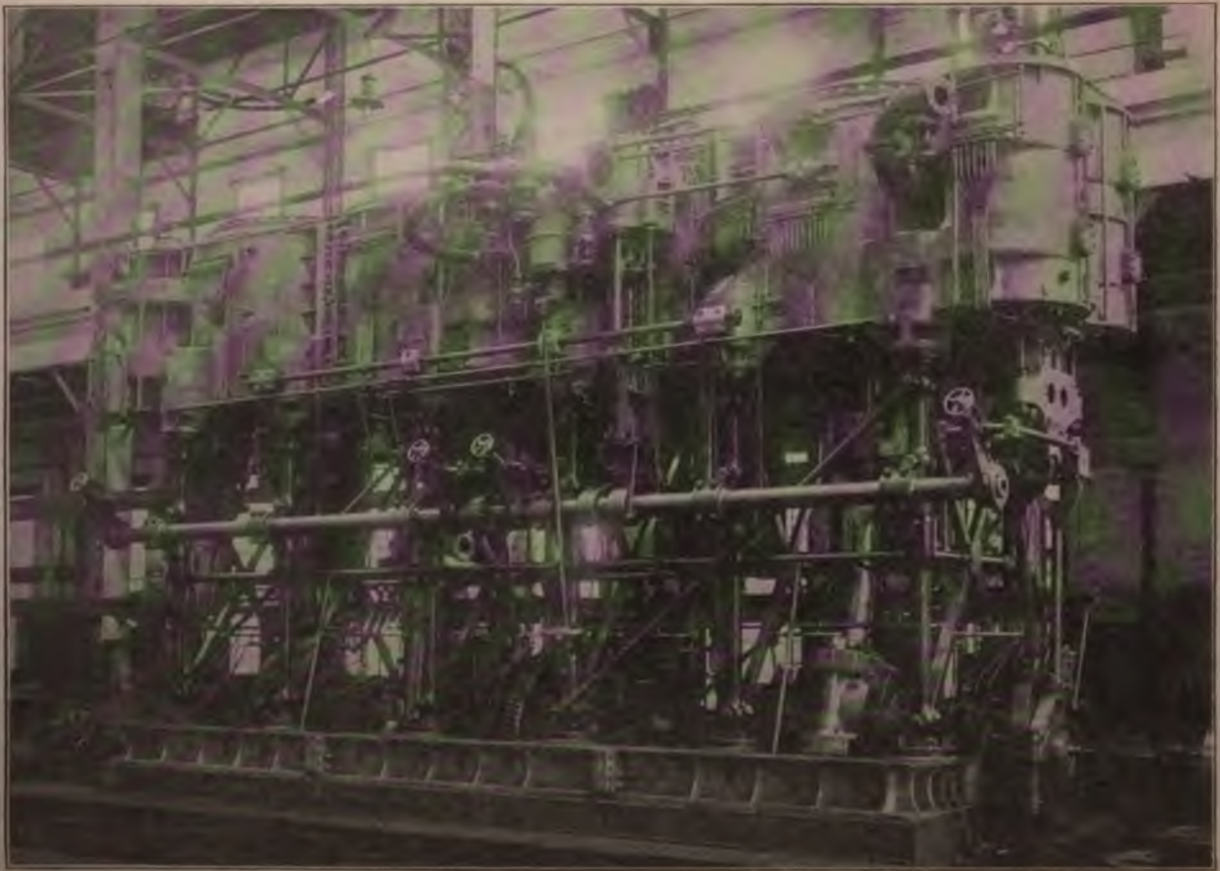
The ease of making repairs depends upon the type of boiler. The sectional type can usually be repaired more readily than others.

These boilers have several disadvantages among which may be mentioned the following :

1. Tendency to prime.
2. Difficulty of feeding.
3. Sensitiveness to corrosion and dirt.
4. Difficulty of repairing tubes.

These defects are reduced to a minimum if the boiler is of good design, well managed and constructed of best material.

Launch Boilers. The boilers used in torpedo boats, yachts and launches should be safe, light, compact and economical. Also they should be capable of supplying dry steam at high pressures. Small vertical fire-tube boilers are sometimes used but the water-tube boiler is better adapted to this work. The water-tube boilers already described are built in small sizes and generally give satisfaction. Perhaps the most used boilers for fast launches, yachts and small vessels are the Ward and Mosher. These boilers are similar in general principles to most marine water-tube boilers but are made small, light and compact.



ONE MAIN FOUR-CYLINDER TRIPLE-EXPANSION ENGINE ON U. S. S. WEST VIRGINIA.

MARINE ENGINES.

The propulsion of ships by means of steam has been a subject of much interest and experiment during the last hundred years. The marine engine was at first a crude piece of machinery very bulky and wasteful of steam; but through the perseverance and skill of engineers, the marine engine of to-day is finely finished, compact, powerful and economical.

As in stationary and locomotive engines, the marine engine must fulfil certain requirements, and in order that it may do so the engineer must overcome certain obstacles and restrictions.

The first object of a marine engine is to propel the vessel through water at the required speed. It must also be so designed and constructed as to be readily reversed. In order to be commercially successful the engine and propelling apparatus must be suited both to the ship itself and to the required service.

Almost all vessels propelled by steam obtain their motion by the projection of a mass of water in the direction opposite to that of the vessel; the exceptions being so few and unimportant as to require no discussion. The water is usually projected in one of three ways:

1. By one or more wheels called **screw propellers** at the stern of the ship.

2. By one or more (usually two) **paddle wheels** outside of the boat.

3. By some device (usually a pump) which causes the water o issue in jets from orifices in the stern of the ship. This is alled **hydraulic propulsion.**

The oldest of these three forms, is the paddle wheel and alough the screw propeller is far better for sea-going ships, the ddle wheel is still used for certain kinds of service. Jet prolsion has not yet become common; the principal reason being space used for the machinery and the large openings required he sides of the ship.

The screw propeller is the most common means of propulsion and as it seems to be well adapted for the work, this type of machinery is worthy of the most attention.

About the beginning of the nineteenth century, many scientific men and mechanics turned their attention to the application of steam to navigation. They met with partial success but in almost every case the project was abandoned after the first unsuccessful trial.

Among these experimenters was an American named Robert Fulton. He was not the first to propel a boat by means of steam but he was the first to make steam navigation a success. Unlike those who abandoned their work after one or two unsuccessful trials he had perserverance enough to continue until his efforts were successful. In 1803, while in Paris, he constructed a small steamboat the trial trip being made on the Seine. The experiment was so successful that he had an engine built in England and then returned to America. In the spring of 1807 the "Clermont" was launched and the English engine put aboard in August. This boat was 133 feet long, 18 feet beam and 7 feet in breadth. The "Clermont" made a trip from New York to Albany (about 150 miles) in 32 hours and returned in 30 hours. The sails were not used on either occasion. This was the first successful long trip ever made by a steamboat.

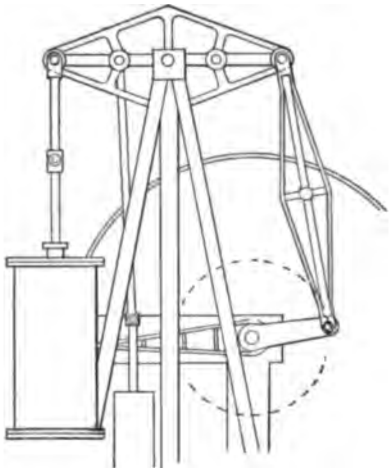


Fig. 1.

The engine of the "Clermont" was coupled to the crank shaft by a bell crank and the paddle wheels were connected to the crank shaft by gearing. The cylinders were 24 inches in diameter and of 4 feet stroke.

Fulton afterward built several steamers the largest one measuring 2,475 tons. This vessel was built for the United States Navy and was a very large steamer for that period.

While Robert Fulton was building steamers with success, Stevens of Hoboken built a steamboat which showed great merit. He used a horizontal sectional water-tube boiler with a working pressure of over 50 pounds per square inch. The usual pressures of the time were 5 to 7 pounds. His engine was direct-acting, high pressure and of the condensing type. The most remarkable feature was the use of a screw propeller of four blades.

In Stevens' second boat, the engines were of the same type as before, but twin screws were used instead of the single screw. Although the screw propeller was introduced as early as 1804, it was practically given up, and for about thirty years the paddle wheel was the principal means of propulsion.

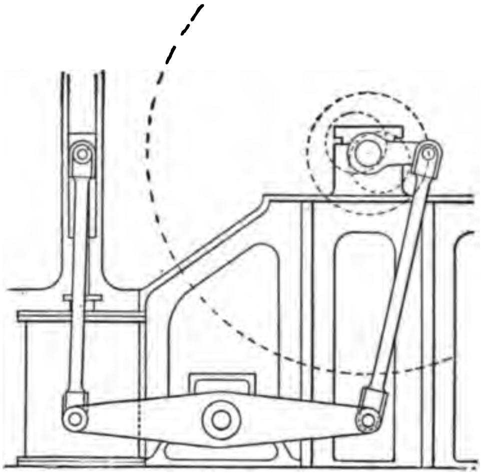


Fig. 2.

As the **beam engine** of Savery and Watt was the first to become successful, naturally some form of this type was the first to become common for paddle wheels. In the beam engine shown in Fig. 1, the motion passes from the piston-rod to a crosshead, and then is transmitted by a rod or link to one end of the beam; from the other end of the beam it is transmitted to the crank pin and shaft by means of the connecting-rod. These engines are well suited for side-wheel paddle steamers and have been used on river and harbor boats for many years. A modification of the beam engine is the **side-lever engine** shown in Fig. 2. This type was made in two forms, the true side-lever as shown in Fig. 2 and the "Grasshopper" engine. The latter differed from the former in that the lever was fulcrumed at the end instead of in the center. This engine possessed several advantages; a long stroke in a shallow ship, simplicity and consequently low first cost and little care. The main objections were its weight and bulk.

The **oscillating engine,** much used in England, was well adapted for paddle wheels. It is shown in Fig. 3. The cylinders are located below the shaft and are swung on trunnions. The piston-rod being connected directly to the crank shaft, makes fewer parts possible, as there are no guides, crosshead nor connecting-rod. Compactness and simplicity are among the advantages; the disadvantages being the difficulty in obtaining early cut-off and liability of the trunnions to leak. This type of engine could be used in an inclined position, but it worked best when vertical, that is, the piston-rod vertical when the piston is at the end of the stroke. These were the principal forms of early vertical engines.

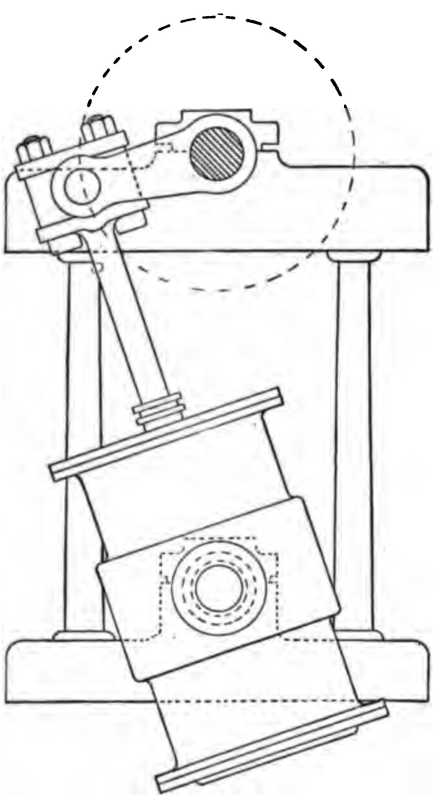


Fig. 3

Another type is the **diagonal or inclined engine.** This engine, shown in Fig. 4, is simply a horizontal engine set in an inclined position, to suit the height of the shaft at one end, and the frames of the ship at the other. It takes up a large amount of space in the fore and aft direction, but is very convenient when space is not one of the objects of design.

Of the other types of horizontal engines, **Penn's trunk engine,** shown in Fig. 5, has one striking peculiarity. It has no piston-rod; the connecting-rod hinges on a pin or gudgeon in the center of the piston. Inside of the cylinder and concentric with it is a cylindrical case or trunk which is attached to the piston and passes through stuffing boxes in both ends of the cylinder. This trunk serves as a support for the piston and makes an equal area on both sides of the piston exposed to steam. This engine is light and compact, and for low steam pressures, is economical. However, if the pressure is high, the friction of the large stuffing boxes is great; if the glands must be made very tight, the engine may be stopped. Again the loss of heat from the alternate heating and cooling of the large surface of the trunk is considerable.

The **return connecting-rod engine,** Fig. 6, is another form of the horizontal type. In this engine the connecting-rod is on the opposite side of the crank shaft from the cylinder. There are two piston-rods, one above the shaft on one side of the crank, and the other below on the other side. The piston-rods are fastened to a crosshead at the center of which is coupled the connecting-rod. This type of engine has some advantages and many disadvantages. It can have a long stroke since the cylinder may be near the shaft. It is not adapted for compounding as the cylinders cannot be made of the proper ratio without difficulty. The double number of stuffing boxes and other parts, together with the short eccentric-rod, make this engine undesirable.

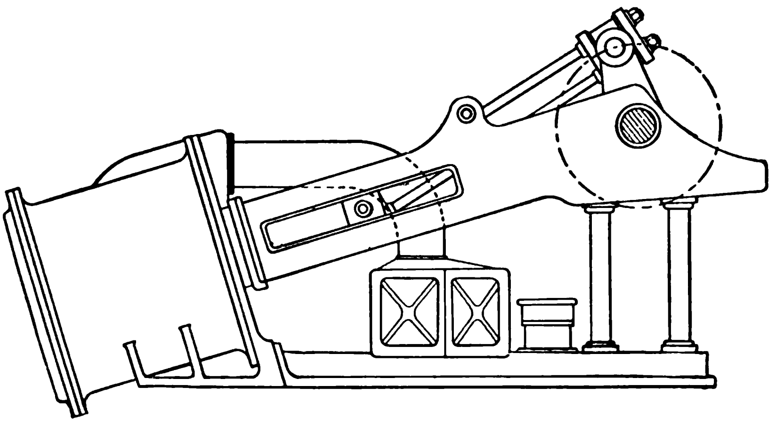


Fig. 4.

The forms of engines already described were the results of early attempts to solve the problem of steam navigation. When, about the year 1840, the screw propeller began to gain favor, many experiments were made to determine the best type of engine. With the rapidly-revolving screw, in place of the slow paddle wheel, and the change in location of the shaft, a new type of engine was necessary. A change was made from the long stroke, heavy, low-speed engines to the small, light, high-speed type. This change was not made at once, but occurred slowly and with many blunders. During this time two other important changes took place. The increase of steam pressure from 10 or 15 pounds to 50 or 60, and the change from the jet condenser to the surface condenser. This latter change was of great advantage because it allowed the use of higher steam pressures which before were dangerous on account of scale.

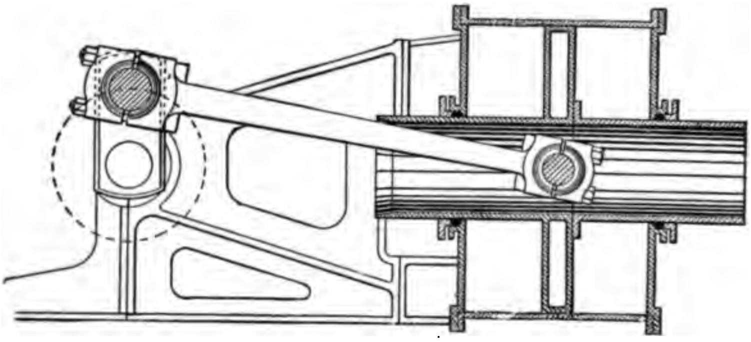


Fig. 5.

With the higher steam pressure was produced still another important advance. It became known among engineers that one of the greatest causes of loss in the engine cylinder was the initial condensation of steam necessary to raise the temperature of the

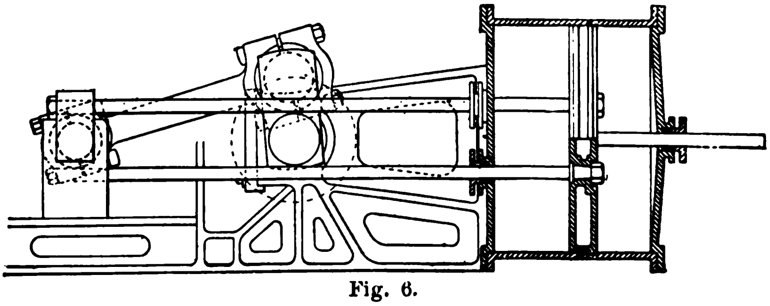


Fig. 6.

cylinder walls. The great expansion desirable made the cylinder walls of low temperature at exhaust. This loss was prevented to a great extent by dividing the expansion among several cylinders.

These changes, higher steam pressures, surface condensers, and multi-expansion engines completely revolutionized the marine engine. Although there are a few beam engines now in use and some of the older types of horizontal engines are occasionally

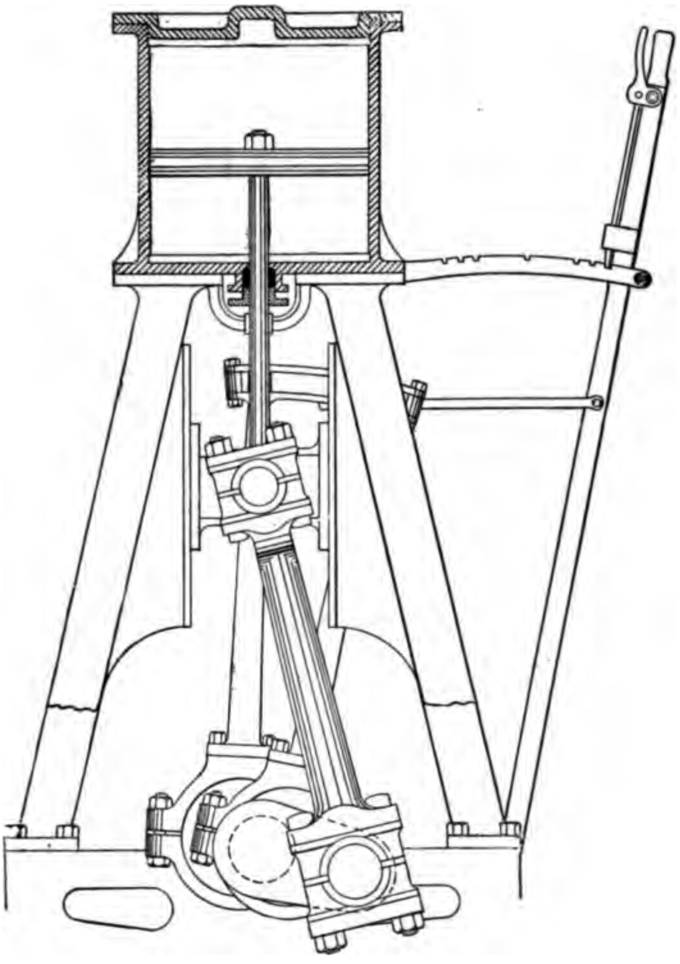


Fig. 7.

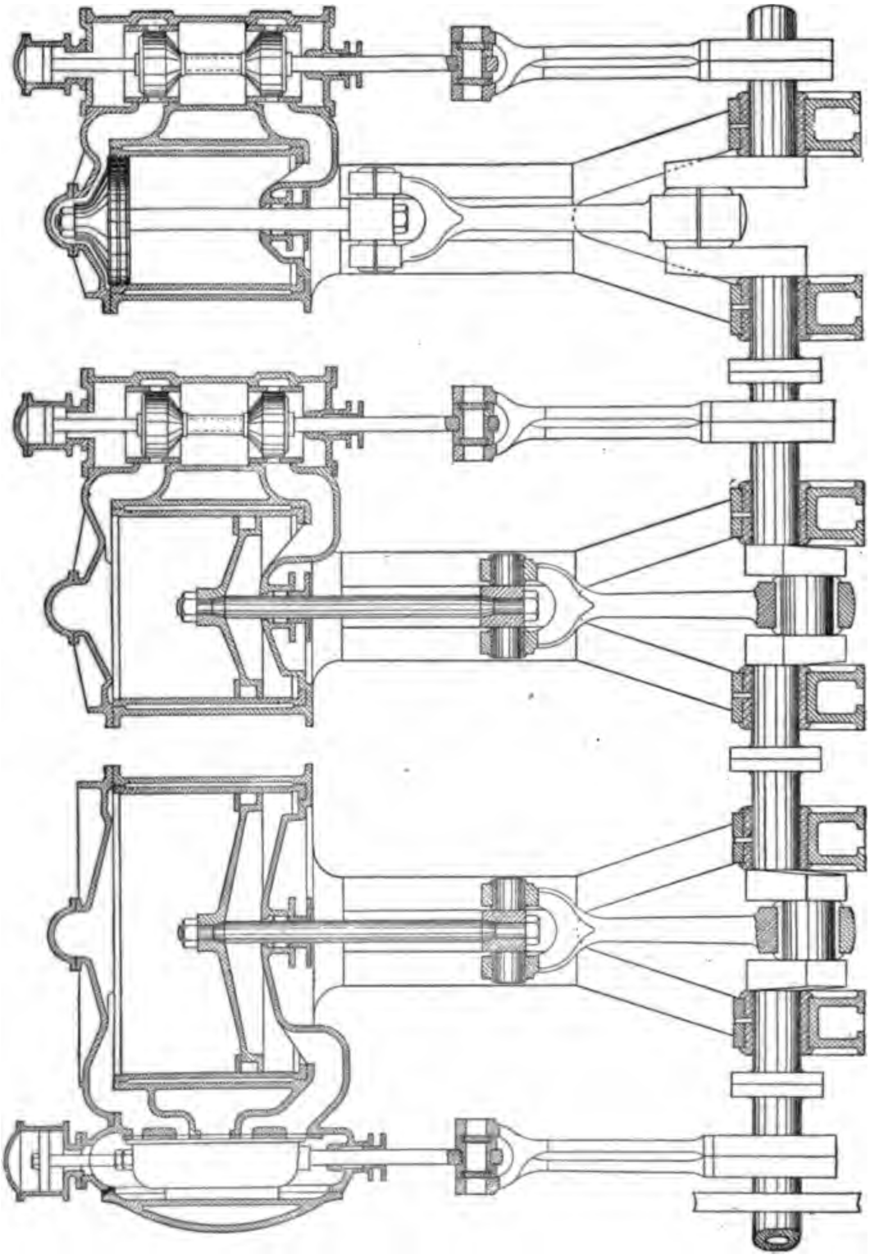


Fig. 8.

seen, the modern sea-going steamer is fitted with high pressure, multi-cylinder engines fitted with surface condensers and either cylindrical tubular boilers or water-tube boilers. These engines are direct-acting, vertical and of high piston speed.

The first screw engines were horizontal, working with a steam pressure of 20 to 25 pounds per square inch. The vertical type soon took the place of the horizontal because of the difficulty of fitting horizontal engines in ships.

A vertical engine for a launch is shown in Fig. 7. This engine has the same parts as the horizontal engine; piston, piston-rod, connecting-rod and crank. The chief difference is the frame. The cylinder is supported by a substantial upright framing which consists of a large back frame and a light front column or heavy frames as shown in Fig. 7 shaped like the letter A. The engines may have two guides as shown or but one guide. The positions of the links and eccentrics are changed by means of a lever but in large engines the link is shifted by means of a small steam engine or by worm gear and levers.

Fig. 8 shows the section of a triple expansion engine. The high pressure cylinder and intermediate cylinder are fitted with piston valves and the low pressure with a double ported slide valve. The pistons are of cast steel. The three cranks on the hollow steel shaft are placed 120° apart.

MULTI CYLINDER ENGINES.

The engines now used for marine work are compound, triple expansion and quadruple expansion, the triple expansion being the most common.

The advantages of the multi-expansion engine are briefly: The decreased loss due to cylinder condensation, the more even turning moment on the shaft and the reduction of pressure on the piston and consequent reduction of weight, friction, etc.

COMPOUND ENGINES.

The cylinders of compound engines are generally arranged in one of the three ways shown in Fig. 9. The **tandem or steeple** arrangement is shown at A; in this type both pistons are on the same piston rod and consequently there is but one crosshead and only one crank. The steeple engine is not expensive on account of the few parts, but as there is only one crank the turning moment is the same as with the single cylinder engine. In A the arrows show the direction of the steam.

At B, the **cross compound** arrangement is shown. This type is often called a **fore and aft** compound. There are two cranks which are placed at right angles to each other. For this reason a receiver is necessary. The advantages of this type are the reduction of pressure on a piston and the more even turning moments; however, these engines having more parts are more expensive and they require more floor space than the tandem. Steam enters the high pressure cylinder and after pushing the piston through a stroke is exhausted into the receiver from which it enters the low pressure cylinder, is further expanded and then goes to the condenser.

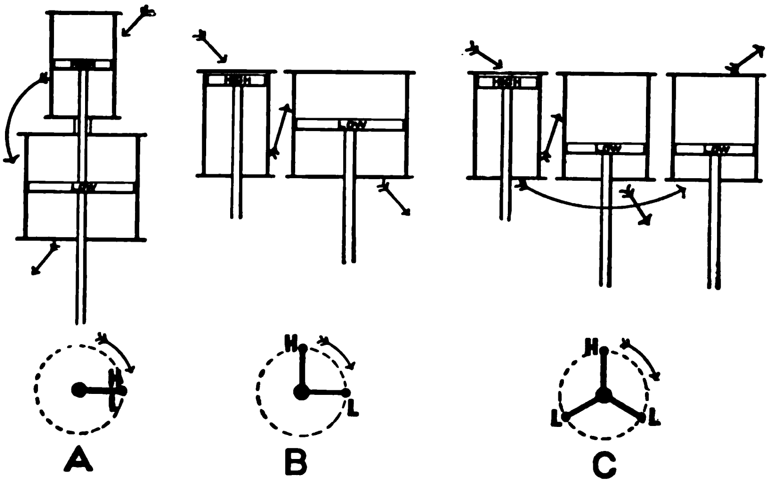


Fig. 9.

The third arrangement C, called the **three cylinder compound**, consists of one high pressure cylinder and two low pressure cylinders. The high pressure cylinder is sometimes placed between the two low pressures. The cranks are usually set 120° apart and cause a more even turning movement than either of the compound arrangements shown at A or B. If a compound engine is to develop a large power the volume of the low pressure must be considerable; by dividing it, each cylinder may be made smaller and therefore more easily manufactured.

The **receiver** of a compound engine is the space between the high pressure piston when at the end of the stroke and the back of the low pressure valve and includes the ports of the high pressure cylinder and the pipe which leads from the high to the low. Formerly large reservoirs were fitted as receivers but it is now the custom to make the pipes between the cylinders large as experience has shown the volume to be sufficient. The *capacity* of the receiver does not effect the total power of the engine but the effect of the size is shown on the back pressure line of the high pressure diagram and the admission line of the low pressure. As the volume of the receiver is increased the back pressure line of the high becomes more nearly straight, and the admission line of the low more nearly parallel to the atmospheric line.

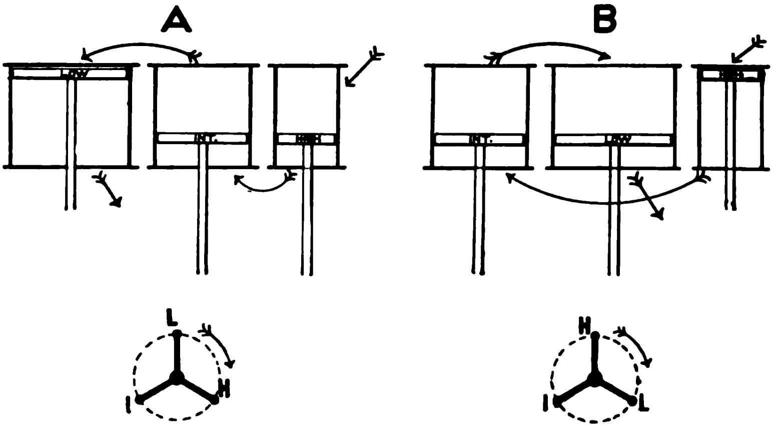


Fig. 10.

Triple expansion engines have two receivers called the first receiver and the second receiver. The same principles apply to the receivers of triple expansion engines as to compound engines.

TRIPLE EXPANSION ENGINES.

The triple expansion engine having three or more cylinders may have many different arrangements according to the fancy of the designer and the space in the ship. The three crank engine is the most common. The arrangement at A. Fig. 10 shows the natural sequence. It is the most used type; the steam going directly from one cylinder to another with a minimum amount of piping. The arrangement shown at B is similar to that of A but requires more piping. Sometimes the high pressure cylinder is placed in the middle. In the three crank engines the cranks exert an even turning movement on the shaft as they are usually placed at 120° apart.

Triple expansion engines may have but two cranks. A common arrangement of this type is shown at A, Fig. 11. The cranks are placed at right angles to each other which does not permit of an even turning movement, especially as it is difficult to divide the power equally between the two cranks. It has the advantage of expanding the steam in three stages and is an easy way to make a steeple compound into a triple expansion. By using two high pressure cylinders, one over the low and one over the intermediate, this form is much improved.

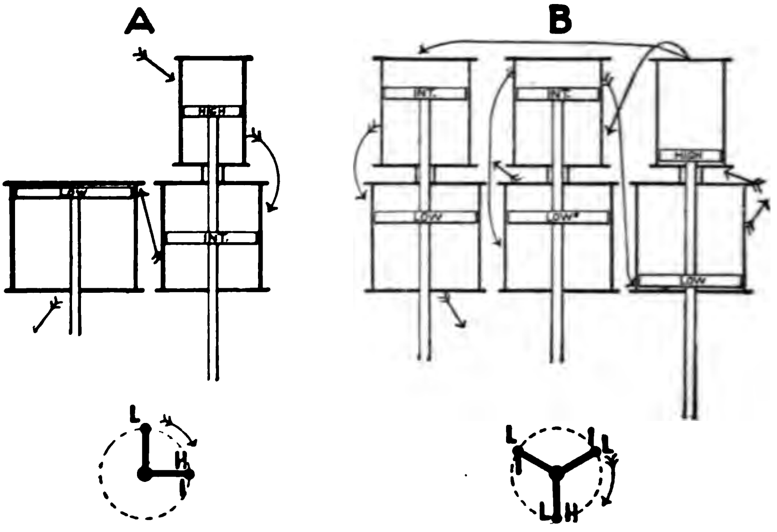
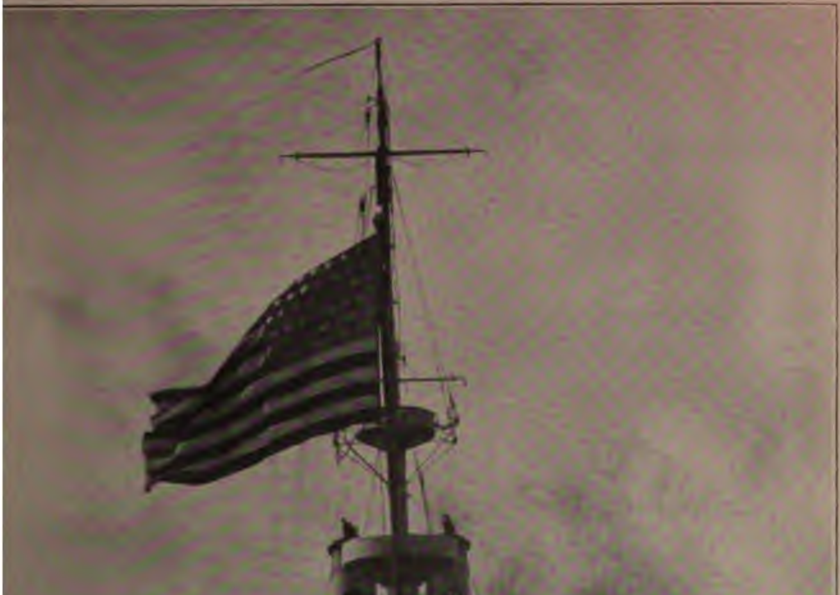


Fig. 11.

An arrangement for very large triple expansion engines is shown at B, Fig. 11. In this case there are three low pressure



U. S. BATTLESHIP ALABAMA.

Displacement, 11,525 tons; 11,366 horse-power; twin screws; 18 guns.

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cylinders and two intermediate. The large volume of the low pressure is thus divided among three of moderate size. Triple expansion engines are seldom made in very large sizes as twin screws are often used and in some cases each shaft has two separate engines. Thus in the U. S. S. "New York" there are four separate triple expansion engines, two for each screw.

QUADRUPLE EXPANSION ENGINES.

The quadruple expansion engine is a further development of the compound engine. The advantage gained by expanding the steam in four stages is slight unless the boiler pressure is at least 200 pounds per square inch. Even at this pressure the triple expansion engine is almost as economical and the increased first cost of a quadruple expansion engine often equals the slight gain in economy. The many cylinders of the quadruple expansion engine make it possible to use many combinations. An arrangement for a four cylinder quadruple expansion engine is shown in Fig. 12. The cranks are placed 90° apart. The four cranks are an advantage as far as turning moment is concerned, but the floor space occupied is considerable. The quadruple expansion engine can have two cranks; this plan, however, is not generally considered as good as the three crank triple, except in the floor space saved.

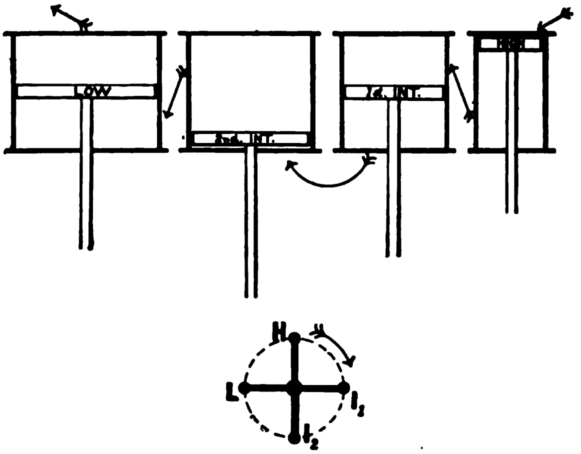

Fig. 12.

As the water-tube boiler is becoming more and more common, very high pressures can be carried with but slight risk. This increase of pressure will probably cause the quadruple expansion engine to take the place of the triple expansion in the same way that the triple expansion has taken the place of the compound.

NAUTICAL TERMS.

The plan of a vessel is represented in Fig. 13. The forward or front part is called the **bow**; the extremity A is called the **stem.** The rear end of the vessel is called the **stern.** If an object is near the bow it is said to be **forward**; if near the center C it is **amidship** and if near the stern it is **aft.** An object placed so that its direction is parallel to the line A B is said to be placed **fore and aft.** Thus, if a compound engine is so placed that the crank shaft lies along the line A B it is called a **fore and aft** compound engine. If, however, an object is so placed that its direction is at right angles to A B or is parallel to E F it is placed **athwartship.** To one standing on the deck and facing the bow, the **starboard** side is on his right and the larboard or **port** side is on his left.

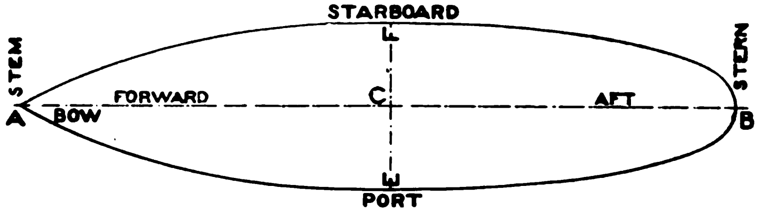

Fig. 13.

The width of a vessel E F is its **beam** and the perpendicular distance from the lowest part of the vessel below the water line to the surface of the water is called the **draught.** The length of a vessel may be measured on the water line, between perpendiculars or over all. The beam, draught and length are expressed in feet and inches. The **displacement** of a vessel is equal to the weight of water that it displaces and is usually expressed in tons of 2,240 pounds. The displacement varies with the draught because the deeper the hull sets in the water the greater the amount of water it will displace. To find the displacement in tons, divide the number of cubic feet under the water line by 35. If the vessel is in fresh water divide by 35.93.

The **speed** of a ship is sometimes expressed in miles per hour; the mile containing 5,280 feet. More often, however, it is expressed in **knots** per hour. The knot contains 6,080 feet and is equal to about $1\frac{1}{6}$ miles. Whether the speed is expressed in miles or knots, it is always understood to mean per hour.

DETAILS.

The Cylinder. The steam cylinder for a marine engine is shown in Figs. 8 and 14. The cylinder consists of three distinct parts; the shell or outer casting, the liner and the cover.

The shell is the casting which encloses the liner in which the piston works. The shell also includes the bottom and the ports or passages through which steam enters and leaves the cylinder. The shell casting is very complicated and for this reason steel is seldom used. Cast iron that runs freely is the best material This cast iron is suitable for the complicated shape but is not hard enough to form the working surface. At the side of the barrel the casting forms the steam and exhaust ports. If a piston valve is used the casting is made of such a shape that the circular seats may be fitted. If a slide valve is employed the cylinder terminates in a flat face, called the cylinder face, upon which the valve slides. As the iron of the cylinder shell is too soft for a wearing surface a false face of hard, close-grained cast iron is fitted to the casting as shown in Fig. 8. The casing which encloses the valve is sometimes cast with the shell and has a removable cover or is made entirely separate and bolted to the casting.

The bottom or crank end of the cylinder is usually cast with the shell although this portion is sometimes made separate like the cover. In large cylinders a manhole is placed in the bottom so that the inside may be examined without removing the cover and piston. In the center of the bottom is a circular hole in which the stuffing-box is fitted. This hole also facilitates the boring of the cylinder. The feet or lugs to which the columns are secured are cast on the bottom.

The cover is fitted to the top or open end of the cylinder.

and is usually of steel so that it will be strong and light. Sometimes both the cover and bottom are cast hollow, the space forming the steam jacket, but more often it is a single thickness strengthened by radial ribs. The shape of the cover depends upon the kind of piston used and upon the arrangements of the steam ports.

The liner or working barrel is a cylinder or bush of hard, close-grained cast iron or forged steel. It is usually fastened in the cylinder shell by flanging the lower end and fitted with set screws or bolts as shown in Fig. 15. The top end is left free to expand. The joint is kept steam tight so that steam will not pass from the jacket to the cylinder. The methods of construction are shown in Figs. 15 and 16. The methods shown in Fig. 16 employ a copper ring secured by set-screws. These methods make a good lasting joint and the copper allows for expansion.

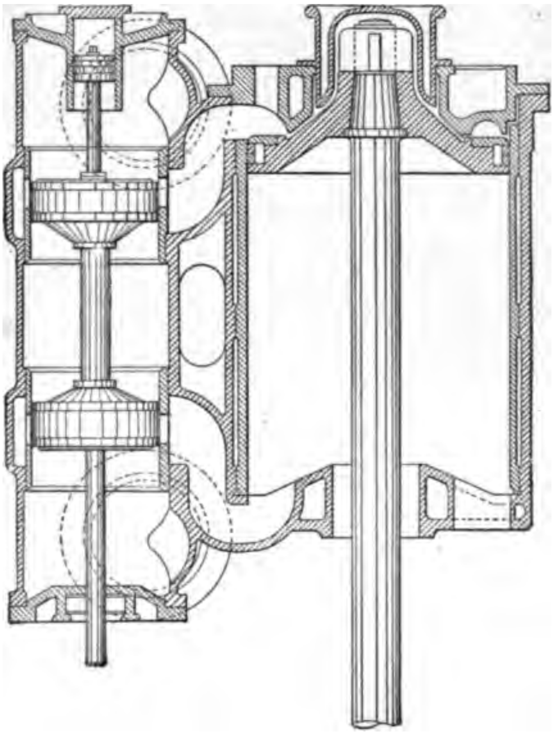

Fig. 14.

The space between the liner and the shell is from $\frac{3}{4}$ to $1\frac{1}{4}$ inches. It forms the steam jacket which reduces cylinder condensation and aids the warming of the cylinder previous to starting. In some cases the inner and outer casing have been made in one casting, but this causes a very complex casting and much trouble from unequal expansion. Also the separate liner allows the use of a harder iron or steel as the wearing surface. Another advantage of the separate liner is the ease with which it can be replaced or re-bored when worn.

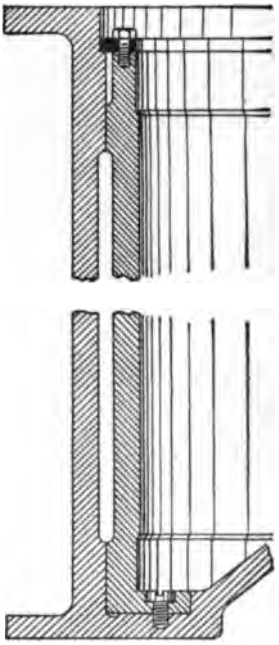

Fig. 15.

Cylinders of large marine engines are usually covered with some non-conducting material to prevent loss of heat by radiation. If high pressure is used the lagging must be incombustible, at least in the portions which are close to the hot surfaces.

Stuffing-boxes. In order that the piston-rod may enter and leave the cylinder without causing leakage, stuffing-boxes are fitted to the bottom of the cylinder and to the cover when the piston-rod is prolonged and passes through it. The principal requirement of a stuffing-box is that it should allow the rod to move freely without leakage.

Stuffing-boxes vary in detail but the principle is the same in all. Fig. 17 shows a simple form. A bush *b* is fitted where the rod passes through the bottom of the cylinder. This is usually of brass, gun-metal or babbitt. The gland *g* is fitted to the outer end of the stuffing-box and is adjusted by bolts. The space *l* between the bush and the gland is filled with some kind of packing. This is usually in the form of rings which encircle the piston-rod. When the gland *g* is pushed inward by means of the nuts, the packing is spread out laterally and fills the space. The farther the gland is forced in, the tighter the packing grips the rod. The tightness should be adjusted so that the rod will move with little friction but it must be tight enough to prevent leakage.

The material used for packing depends upon the conditions. With low pressure steam asbestos fibre has been used with more or less success depending upon the conditions. For high pressure

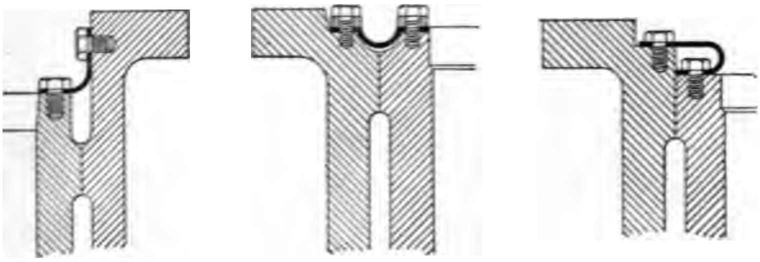

Fig. 16.

steam and continuous work, metallic packing is a necessity. A stuffing-box fitted with metallic packing is shown in Fig. 18. The packing is in the form of rings of white metal having a triangular section as shown at W. Each ring is made in two lengths. Alternating with these are rings of gun-metal G also of triangular section. A ring F containing a number of spiral springs is fitted next to the gun-metal bush. These springs tend to keep the metallic rings in contact with the rod by means of the pressure on the inclined surfaces. The gland V is screwed down to the stuffing-box and held in place by nuts on the bolts. This gland keeps the packing rings in place. The pressure of the springs takes up the slight wear. The gland V is recessed to form a space for ordinary asbestos packing which prevents the escape of any steam that may leak past the metallic rings. The gland H need not be screwed in very tight. A second recess is formed in the gland H for a soft gasket to hold oil or water lubricant on the rod.

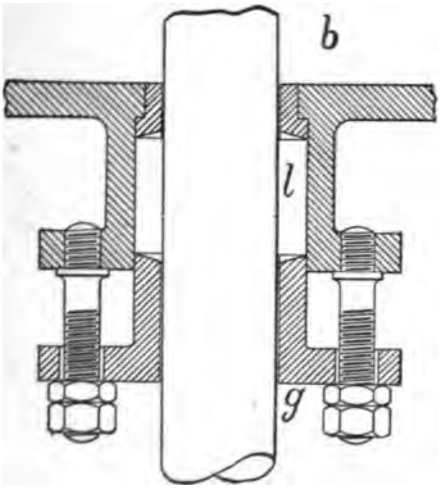

Fig. 17.

Pistons. The piston is a disc which is secured to the end of the piston-rod and on which the steam acts. Pistons were made of cast iron but in most modern marine engines they are of cast steel. Cast steel pistons are made of a single thickness and are much lighter than a cast iron piston of equal strength. Fig. 19 shows the general form. The main part or body B is dished to secure stiffness. At the circumference, which is made quite broad, there is a flange F which carries the packing ring R. The packing ring is made of hard, close-grained cast iron or phosphor bronze. It is cast as a hoop, is turned to the correct diameter and then cut at one part. It is pressed against the liner by the springs. The junk ring J holds the ring and springs in place. The ring R is carefully fitted and scraped to form a steam tight bearing with the surfaces of the junk ring and flange. The junk ring is secured by bolts which are sometimes screwed into gun-metal plugs M, Fig. 20, instead of into the piston itself. This construction is advantageous if the ring must be removed frequently. The bolt heads E are sometimes prevented from slacking back by the light guard ring O which bears against the bolt heads. The guard ring is secured by bolts the nuts of which may be secured by split pins.

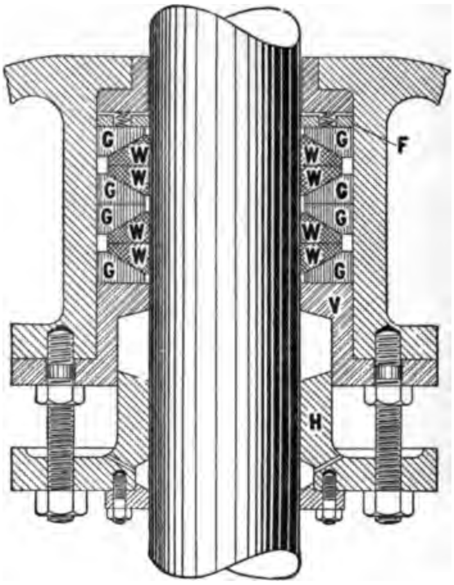

Fig. 18.

In the piston shown in Fig. 19 the packing ring is pressed against the liner by springs of the coach spring pattern. As the pressure is likely to vary at different points, spiral springs as shown in Fig. 21 may be used. These are sometimes preferred. Another plan is to use a continuous spring which encircles the entire piston.

Sometimes the packing ring is turned to a greater diameter than that of the inside of the liner. A piece is then cut out obliquely and the ring compressed to fit the liner. The elasticity of the ring tends to keep it against the liner. To prevent steam from leaking through the joint a tongue-piece is fitted back of the ring as shown in Fig. 19, at T. The tongue T fits into the slot in the ring, passes across the gap and enters the slot in the other end of the ring. The plate D, Fig. 22, in the same piece with the tongue T is fitted to the inside of the ring. The tongue piece D is fastened to one end of the ring R by screws G, and as it is fastened to but one end the other is free to move.

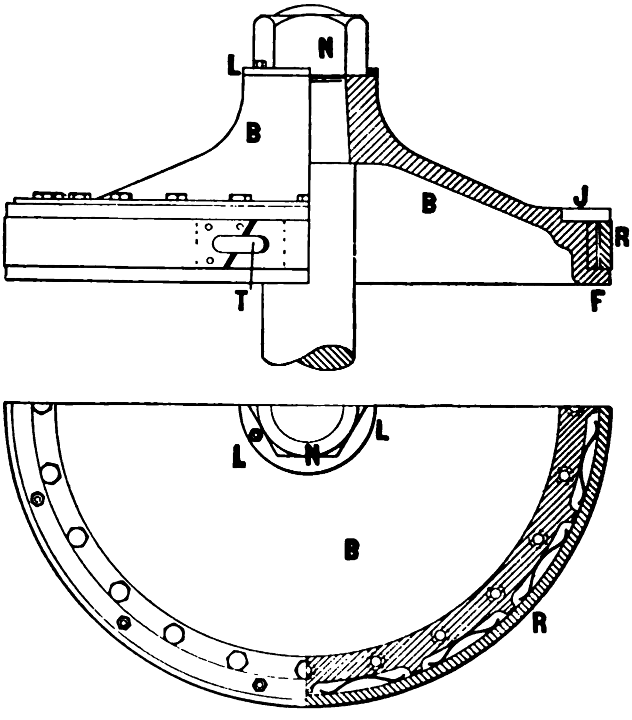

Fig. 19.

The piston-rod is usually made of forged steel. The piston is secured to the rod by a variety of methods, but the simplest is the most common. By this plan a cone of slight taper is formed on the rod and a shoulder formed at the large end as shown in

Fig. 14. The coned end is carefully fitted to a similar hole in the boss of the piston and a nut fitted at the small end of the cone. The nut is used to tighten and hold the piston on the rod. Sometimes the shoulder at the base of the cone is omitted as shown in Figs. 8 and 19. The nut on the end of the piston-rod is kept from slacking back by the guard ring or other device.

ROTARY MOTION.

The marine engine, like the stationary, is a reciprocating and rotary engine. In other words, the steam drives the piston back and forth in a straight line in the cylinder and this motion is converted into rotary motion by means of the connecting-rod and crank.

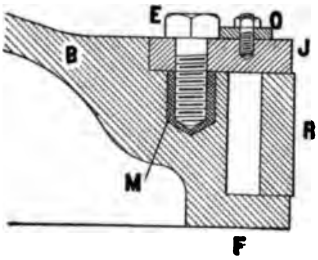

Fig. 20.

The motion of the reciprocating parts is illustrated by Fig. 23 ; one diagram representing the down stroke and the other the up stroke. In these diagrams, P represents the piston, PT the piston-rod, TR the connecting-rod, RS the crank and S the shaft. The end T of the piston-rod is made to move in a straight line by the guide G.

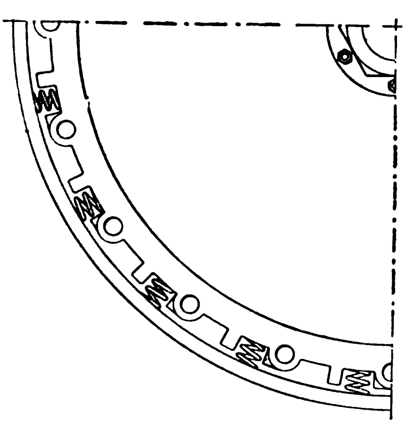

Fig. 21.

Suppose the engine is moving in the direction indicated by the arrows NN. The piston is driven first in one direction and then in the other, but for either direction the force acting along the piston-rod PT is resisted by the propeller. This produces tension or compression in the connecting-rod according to the stroke. The arrows indicate the direction of these forces. The forces acting in the piston-rod and connecting-rod produce a resultant force at the cross-head which is toward the guide, for the direction of rotation shown by the arrows NN. While the engine is turning in this direction the pressure is on the guide as shown during both strokes. If however, the engine turns in the opposite direction the crosshead will tend to leave the guide G or the resultant force will act in the opposite direction. The force acting at the crosshead is resisted by the guide.

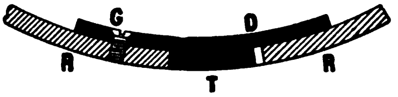

Fig. 22.

Crosshead. The end of the piston-rod terminates in the crosshead to which the connecting-rod is attached. There are many different forms of crossheads depending upon the frame and connecting-rod. In Fig. 7 is shown the arrangement when there are two heavy uprights. The crosshead has a bearing on both frames. For this form of crosshead the connecting-rod is almost always forked, that is, the connecting-rod divides and has a bearing at each side of the crosshead.

In Fig. 8 the crosshead is of the slipper type. In this type the guide is on one frame only and a portion of the crosshead called the slipper, slides on this bearing surface and is held in place in a sort of groove or channel of a shape as shown in Fig. 24. The slipper slides on surface A of the guide plate P which is secured to the frame. While the engine is going ahead the thrust on the crosshead keeps the slipper pressed against this surface. The flanges FF, secured by bolts, resist the thrust when the engine is going astern and keep the crosshead in the channel. Fig. 24 shows that the ahead surface is greater than the astern. This arrangement works well, for a marine engine seldom runs astern at full power for any length of time. The space back of the plate P may be used for the circulation of sea-water to keep the

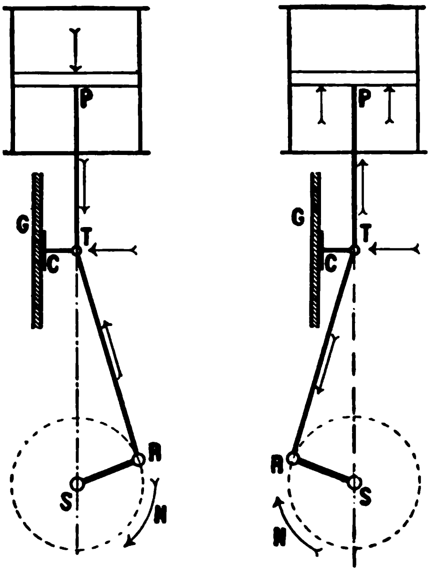

Fig. 23.

plate cool. In some forms of slipper-crosshead the crosshead is built around the guide, which is a piece of steel of rectangular section, instead of being enclosed in the guide. In the crosshead shown in Fig. 7 the astern surface is equal to the ahead surface.

Connecting-rod. The connecting-rod is jointed to the crosshead at one end and to the crank-pin at the other. The rod itself is usually round or rectangular sometimes tapering with the small end at the crosshead. The large end is made to turn on the crank-pin and is formed as shown in Fig. 25. The end is made with a jaw J solid with the rod. The cap C is held to the jaw by two bolts BB which pass through the jaw and cap; the nuts of these bolts are usually prevented from slacking back by some approved locking device. The head and cap are shaped so as to receive the brasses OO which fit the crank pin.

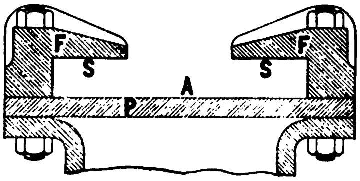

Fig. 24.

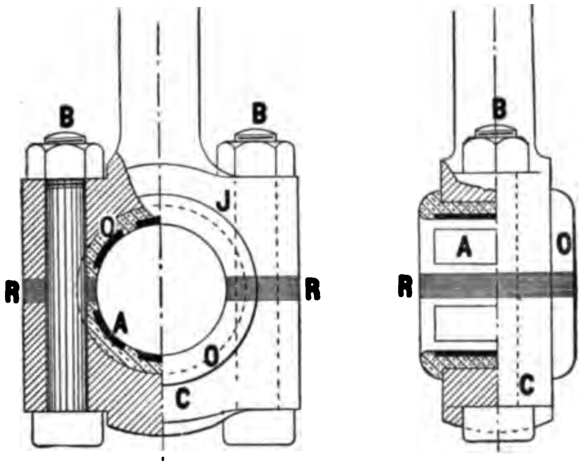

Fig. 25.

These brasses often have white metal strips AA fitted in the wearing surface. The white metal is an alloy which works well and can easily be replaced. The distance pieces or liners R are fitted for adjustment. When the brasses wear, these liners can be taken out and filed thinner but to obtain greater accuracy and lessen the time required the liners are often made up of thin strips of metal so that a thin strip can be removed. The liner may be made of a cast distance piece and several thinner pieces on each side. To obtain smooth working especially at high speed the brasses should be screwed hard to the liners.

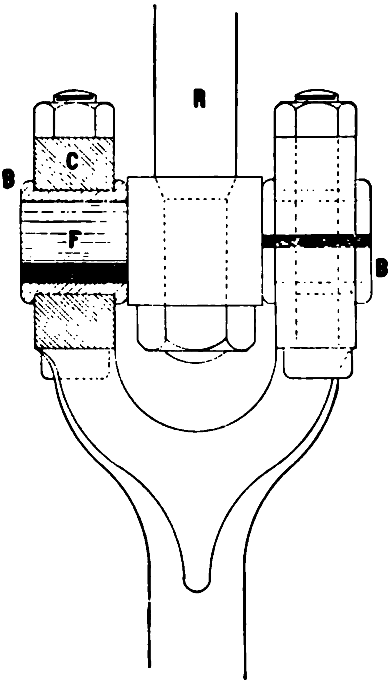

Fig. 26.

If the small end of the connecting-rod is not forked, the end is made similar to the end shown in Fig. 25. When forked it has an appearance as shown in Fig. 26. The end carries a pair of brasses BB in each end which fit the pin F which projects each side of the crosshead. The caps C are held by bolts in the same manner as for the large end. The movement of the pin in the brasses is oscillatory and not rotary; for this reason the brasses are not always fitted with white metal. The pin has a tendency to wear oval and is usually case-hardened if worked in brass or gun-metal.

Crank-shafts. The cranks for marine engines are double, that is, they consist of two crank-arms as shown in Fig. 27. The crank-shafts are made in parts and these parts bolted together; that is, for a three-cylinder triple expansion engine, the crank-shaft would be made in three separate parts, one for each cylinder. These three are sometimes made alike so as to be interchangeable. This necessitates carrying but one spare length. The lengths are fastened together by flange couplings as shown at FF, Fig. 27. To insure the proper alignment one end is filleted into the next length as shown at N. The crank-pin is made of about the same diameter as the shaft. Shafts and crank-pins are usually hollow if they are large; the diameter of the hole being about one-half that of the shaft as shown by the dotted lines. The central portion of the shaft is the least effective in resisting twisting and when it is removed the shaft is almost as strong as when solid. The saving in weight thus effected is equal to about 20 per cent.

Bearings. The object of bearings is to enclose the shaft or journals in parts that are easily adjustable and renewable. The enclosing parts should be made of some material that will not injure the journal, will be strong and firm and that will work with little friction. Brass or gun-metal lined with strips of white metal answers the requirements in most cases. The white metal is usually melted and run into dove-tailed recesses as shown in the various figures and when finished stands just clear of the surface of the brass.

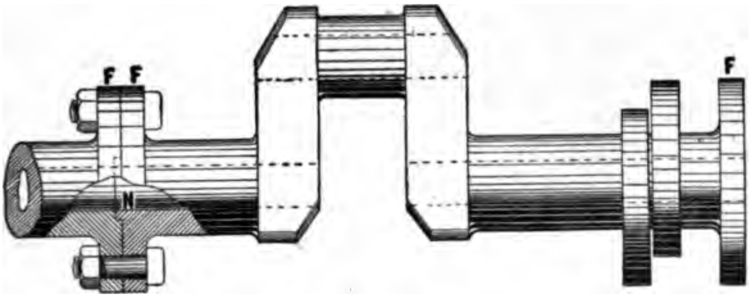

Fig. 27.

The brasses are fitted into the frames or bed-plate as the case may be, the frame being recessed to receive them. In the case of the main bearings, the forces act vertically and the brasses are therefore placed above and below the shaft. In large bearings, the bed for the bottom brass and the bottom of the brass itself are made cylindrical, to facilitate the removal of the brass while the shaft remains in place. To remove the lower brass, the shaft is supported and the brass moved around toward the position occupied by the top brass. Brasses are held in place and adjusted by bolts and nuts. The adjustment is facilitated by the insertion of thin strips of metal between the brasses as with the ends of connecting-rods.

In order to have good working, the bearing surfaces must be large, accurately fitted and adjusted and kept clean and well lubricated. Any dirt that finds its way between the journal and the brasses soon causes wear and perhaps heating. The lubrication also is important. For the main bearings there are several methods; siphon lubricators and various forms of oil cups and boxes being common. The oil finds its way to the inner surfaces of the brasses through oil holes and reaches the various parts of the bearing by channels cut in the faces of the brasses.

Crosshead guides and the connecting-rod bearings are supplied with suitable lubricator cups. The crank-pin and the brasses of the large end of the connecting-rod are moving so fast and continuously that they cannot be oiled as easily as are the other bearings. For this reason, a centrifugal lubricator is sometimes used. The general idea of this device is shown in Fig. 28. The annular casing A shaped as shown is fastened to the crank-arm and communicates with the space E by means of the pipe P. From the space E the oil flows to the surface of the crank-pin by the small holes G. Oil poured into the casing from the outside is forced by centrifugal force from the casing to the crank-pin brasses.

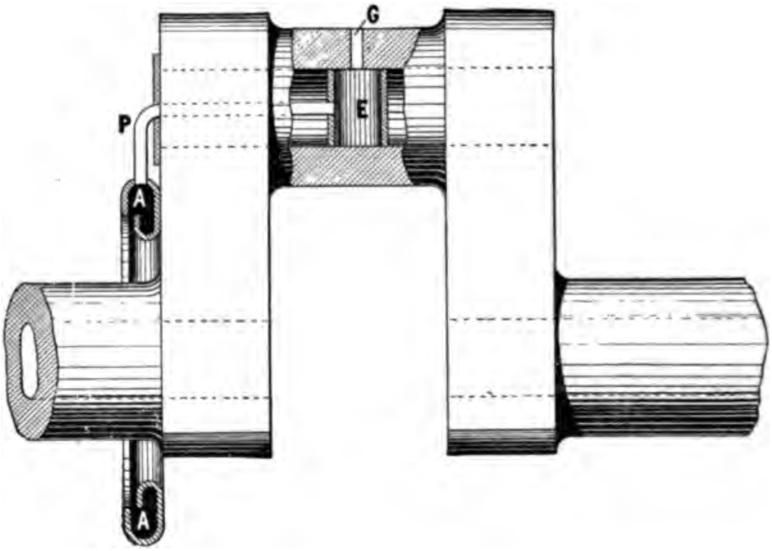

Fig. 28.

Thrust Bearing. While the screw is revolving, the thrust or pressure tends to force the propeller-shaft forward or aft, according to the direction in which the vessel is going. To resist this tendency several collars are forged on the shaft, and these collars revolve in a block called a thrust bearing. Thus we may say that the office of the thrust bearing is to receive and transmit to the ship the thrust produced along the shaft by the revolving of the screw. This bearing is situated near the forward end of the screw-shaft, or in other words, it is just aft of the engines.

A simple form of thrust block is shown in Fig. 29. It consists of a cast iron block R, with a removable cap G. The portion of the shaft that lies in this block is forged with several collars C on it. These collars fit between gun-metal or brass rings B, which are fitted in grooves or recesses turned in the bearing R and the cap G. The rings B are prevented from turning by the tongue pieces F, which are placed at each side between the cap and base. The collars on the shaft press against the after or forward faces of the collars B according as the screw revolves for ahead or astern. In both cases the thrust is taken by the block. The thrust bearing can be adjusted in a fore and aft direction as the bolt holes are elongated. Sometimes the base is cored out so that water may be circulated to prevent heating of the rings. An arrangement for oil lubrication is shown at P, and water may be supplied through the holes A.

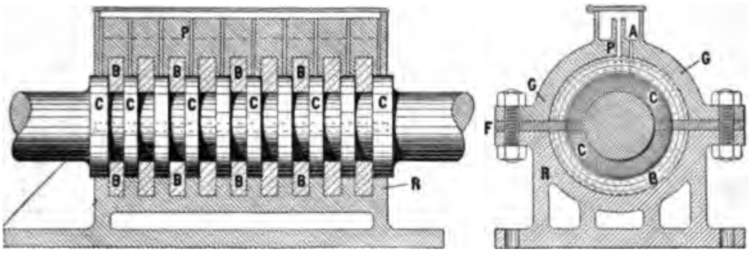

Fig. 29.

It is of great importance that the thrust should be distributed among the rings and not taken by one or two of them. In case a few of the rings take the thrust the pressure is so great that it is difficult to obtain sufficient lubrication to prevent heating. In the thrust block shown in Fig. 29, the thrust rings cannot be easily adjusted, and therefore this form is not used very much.

The thrust block shown in Fig. 30 represents the type most commonly used at the present time. In this block each thrust ring may be readily adjusted without moving any of the others.

There is only a lower part or base as the cap is formed of adjustable collars, which are in the form of horse-shoes. One of these horse-shoe rings is shown in Fig. 31. These rings are placed over the shaft between the shaft collars, and are secured to two large screws on each side by means of nuts which serve to adjust the rings and hold them in place. The horse-shoe collars are lined with white metal for steel shafts and bronze or brass for wrought iron shafts. These linings are usually fitted into recesses formed in the thrust rings.

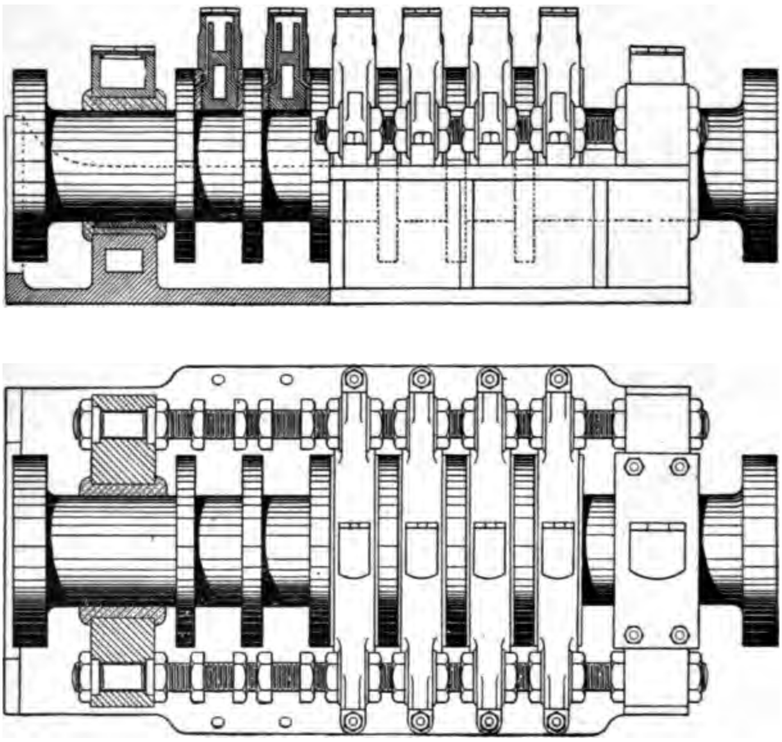

Fig. 30.

The lower part of the base is cored out so that water may be circulated to keep the bearing surfaces cool.

Each collar is supplied with an oil box or cup so that the lubrication will be abundant. The oil should reach the collars at

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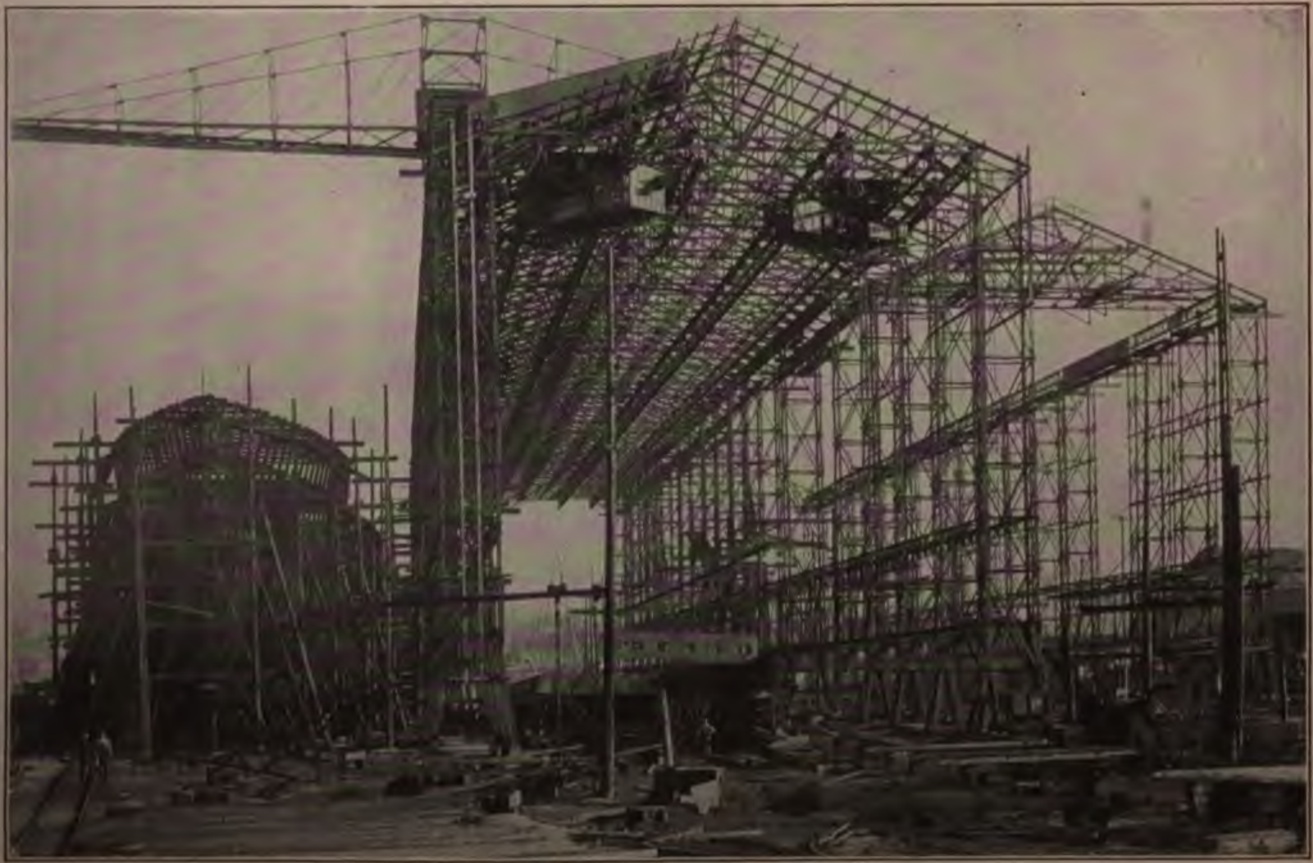
R L



A Modern Shipyard.

the part nearest the center of the shaft because centrifugal force tends to throw it toward the outside edge.

Ordinary bearings are fitted at one or both ends to support the shaft and prevent vibration.

The thrust bearing is generally placed near the engine. The first length of shafting abaft the crank shaft is frequently the thrust shaft. Thus if placed near the engine it can receive proper attention and be kept clean and well lubricated. This bearing is of considerable importance, because if the rings heat they will wear rapidly, and then the whole line of shafting must be thrown forward to take up the wear. In addition to the inconvenience caused by heating, cutting and wear, the friction of a dirty, half lubricated, or poorly adjusted thrust bearing greatly reduces the power delivered to the propeller.

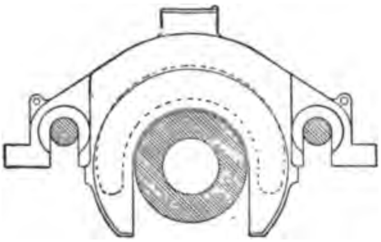


Fig. 31.

The *number of collars* depends upon the size of the shaft, which in turn depends upon the power of the engine, and the ideas of the designer. If the collars are many they will of course be of small diameter. In this case the thrust will probably be taken by several collars, but if for any reason it comes on one or two, the small diameter prevents their acting effectively without heating. The large collars are of necessity of large diameter and therefore expensive to forge, and have higher speed of rubbing surfaces; but the few collars allow a better design of block, and one or two of them are better able to take the whole thrust.

The number of collars is determined from the experience of the designer. To calculate the diameter of the collars, the number is first assumed.

Let n = the number of collars.

D = the diameter of collars.

d = the diameter of the shaft.

P = total load.

p = pressure per square inch of area.

Usually the allowable value of p is limited to about sixty pounds.

The following formula expresses the total load:

$$P = p\left(\frac{\pi D^2}{4} - \frac{\pi d^2}{4}\right)n.$$

Inserting the value of p as 60, we have

$$P = 60 \times \frac{\pi}{4}\left(D^2 - d^2\right)n.$$

$$P = 47\left(D^2 - d^2\right)n.$$

$$\text{Hence } D = \sqrt{d^2 + \frac{P}{47n}}$$

Suppose a shaft is 12 inches in diameter and there are six collars, what should be the diameter of the collars if the total thrust is 41,000 pounds?

$$D = \sqrt{144 + \frac{41{,}000}{282}}$$

$$= \sqrt{144 + 145} = \sqrt{289}$$

$$= 17 \text{ inches, Ans.}$$

STARTING GEAR.

The marine engine must be made so that it will run in either direction as required, and the gear must be so constructed that the engine may be reversed quickly and with little trouble. In a small engine the valve and links may be moved with so little force that a hand lever is fitted, as shown in Fig. 7. In a large engine, especially if large slide valves are used, considerable power is necessary to move the gear. For this reason it is customary to use a small steam engine to assist in moving the links and valves. This arrangement, called the *steam starting gear*, has several forms and the details vary considerably. Fig. 32 shows one form. In order that all the links of a multi-expansion engine may be moved at once, a shaft, called the weigh shaft, runs the length of the engine and is held in bearings on the frames. To this shaft (W in Fig. 32), all the links are connected, so that if the shaft is rotated all the links move together. To this shaft are keyed for each engine two rocker arms, M and N; at the end of N is connected one end of the reach rod X, which is connected at the other end to the centre or to the ahead end of the link. The end V of

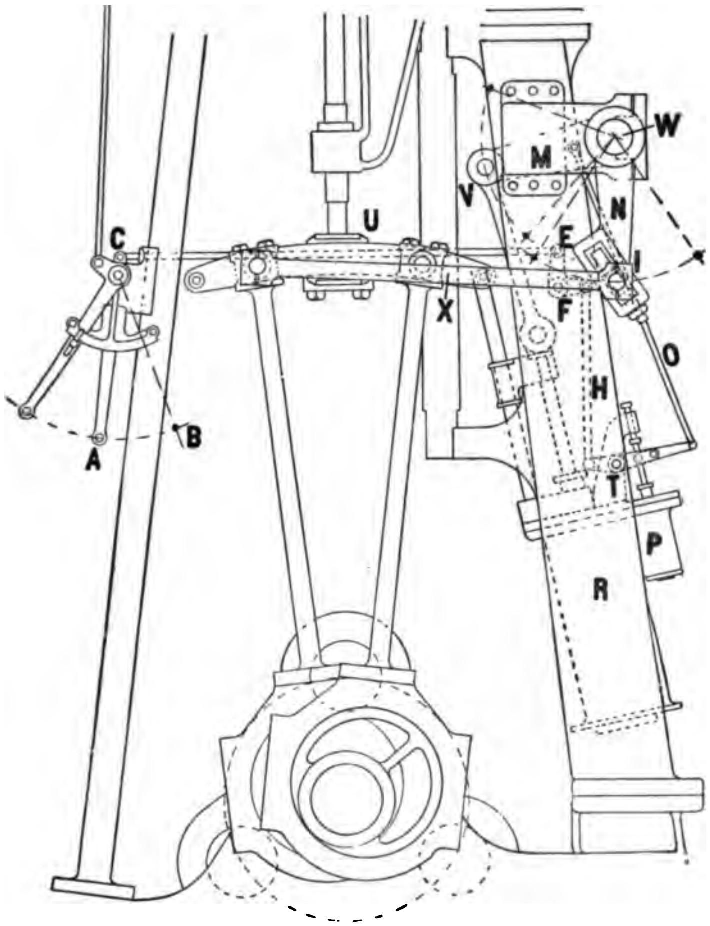


Fig. 32.

the arm M is jointed to the end of the connecting-rod of the small steam engine R. The rod O connects the arm M and the valve of the small engine. It will be seen from the sketch that if M is moved downward, N will move to the right, and as N moves to the right the reach rod and link will also move in that direction.

The action of the gear is as follows: When the handle is moved from A (the mid-position) to B, the point C moves to the left, carrying with it the rod C E. This movement raises the rod H which is connected to the lever fulcrumed at T. When the rod H moves upward the rod O moves downward, which causes the arm M to move downward, thus moving N to the right. As has been stated, the moving of N moves the reach rod and the link. As all the links have similar reach rods and rock arms they also move. When the handle A is moved, the reach rod moves also, but as the power applied at A is not sufficient to move the gear rapidly or to any great extent, it is arranged so that when

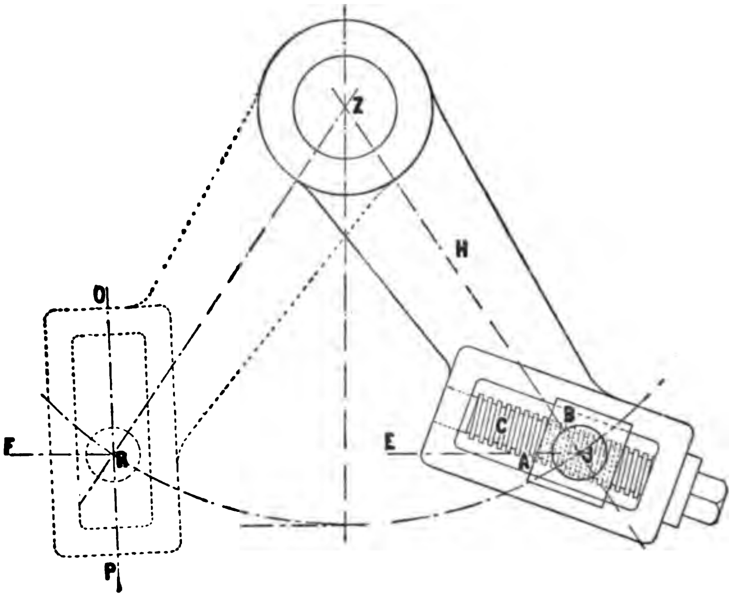


Fig. 33.

the link O moves, the valve P also moves and admits steam to the cylinder R; the piston in R moves its piston-rod, connecting-rod and the arm M. Thus it is readily seen that movement of the handle A moves the link slightly and at the same time starts the engine that aids in the movement of all the links.

From the study of "Valve Gears" we know that linking up shortens the travel of the valve and causes earlier cut-off. In compound and triple expansion engines the links for all the cylinders move the same amount, so that cut-off is altered the same amount in all the cylinders. When working at reduced powers it is often desirable to change the cut-off in one cylinder without changing it in others, or it is often necessary to make a greater change in some cylinders than in others. Expansion valves are undesirable for several reasons, and to accomplish the change in expansion the end of the reversing arm N is made with a slot and block as shown at I Fig. 32 and enlarged in Fig. 33. The reach rod is attached to the block B which can be moved and adjusted in the slot A by the screw C. Thus if the block B is moved, the position of the link is altered slightly which causes a slight change in the cut-off. In Fig. 33, the arm H is shown in the ahead position. From the position of the slot it is seen that this movement can be effected when in this position. The dotted lines show the arm and slot when in the astern position. If the link is in the astern position the movement of the block is vertical and the position of cut-off is not altered as there is no lateral movement. Thus if the link is in the ahead position and arranged for early cut-off and is suddenly shifted into astern position the links will be in full or nearly full gear.

In Fig. 33, the lines F R and E J show the approximate positions of the center of the reach rod. The angle JZR depends upon the amount of movement of the links, and is usually a little less than a right angle.

It is customary to fit a hand-reversing gear so that in case of accident to the steam starting engine, the main engines can be reversed by hand. This gear consists of a hand-wheel on a worm shaft. The worm turns a worm wheel which rotates the arms on the weigh shaft. Provision is made for throwing the worm in and out of gear.

CONDENSERS.

The general description and method of using condensers has already been given in previous discussions. In marine work the surface condensers is used almost exclusively, because with this type the injection water (sea-water) does not mingle with the condensed steam. If the jet condenser were used, the salt water would soon deposit so much salt on the heating surfaces that the boilers could not carry high pressure. Also there would be a loss in efficiency.

The condenser is advantageous for two reasons; it increases the power of the engine by reducing the back pressure, and it allows the feed water to be used over and over again.

The surface condenser is, briefly, a large closed vessel in which is a great number of small tubes. The general arrangement is shown in Fig. 34. The exhaust steam from the low pressure cylinder enters the condenser C and is condensed by the cold water because the latent heat is absorbed by the water. In the surface condenser the cold water may surround the tubes through which the steam flows, or it may circulate through the tubes and the steam surround them. The latter arrangement is the more common. Sea-water enters the vessel through the pipe K and flows to the circulating-pump R, which forces the water into the condenser through the pipe L. After flowing through the tubes it leaves the condenser by means of the exit M and flows overboard. Exhaust steam enters at S, and is condensed by coming in contact with the cold tubes; the water (condensed steam) then

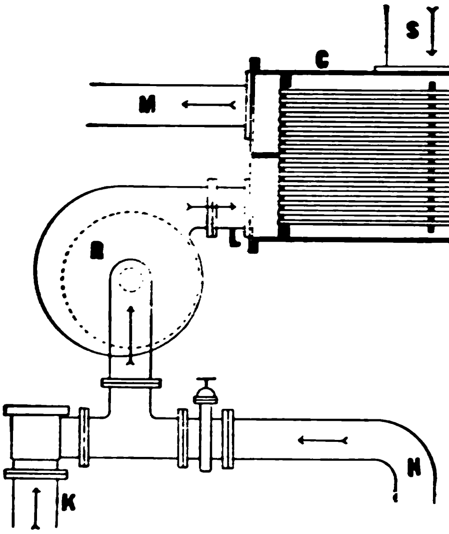


Fig. 34.

falls to the bottom of the condenser and flows to the air-pump B by the pipe E. The air-pump removes the air, vapor and condensed steam from the condenser and forces it through the pipe N into the hot well, from which it goes to the boilers or to the feed tank. The circulating water may be drawn from the bilges through the pipe H.

The **circulating-pump** is usually of the centrifugal type consisting of a fan or wheel which is made up of a central web or hub and arms or vanes, as shown in Fig. 35. The vanes are curved and as the water is drawn in at the central part the vanes throw it off at the circumference. A suitable casing directs the flow. This type of pump is advantageous because there are no valves to get out of order, and as the lift is little, if any, the pump will discharge a large volume of water in a nearly constant stream. The circulating-pump is usually placed below the water line so that the water flows to it. The pump is driven by an independent engine so that the circulating water may cool the condenser even if the main engine is not working.

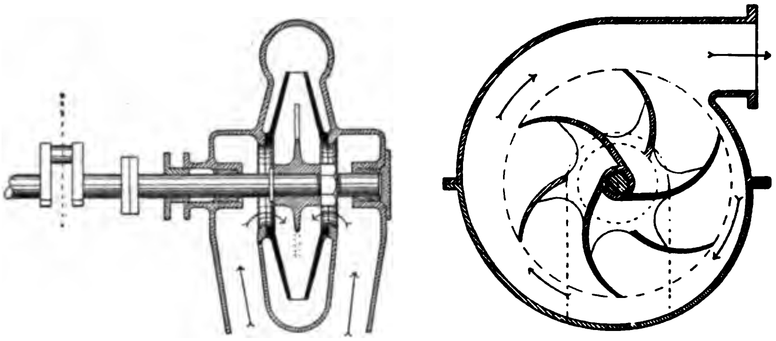


Fig. 35.

The centrifugal pump works more smoothly and with less trouble than an ordinary force pump because it is not reciprocating and it has no valves. The circulating-pump is also piped so that it will pump from the engine room bilges if necessary without the water passing through the condenser. Sometimes two circulating-pumps are fitted to each condenser, each pump being of sufficient capacity to supply the condenser. This arrangement provides for a large bilge pumping power and also duplicates the circulating arrangements.

A suction pipe from the bilge is connected to each pump, and the valves are arranged so that the pump may be cut off from the sea and connected to the bilge or *vice versa.*

When the steam is condensed the water falls to the bottom of the condenser and is drawn out by the air-pump. This pump is usually worked from the crosshead of the low-pressure cylinder. With this arrangement the air-pump cannot work while the main engine is not running, so that the condenser is full of air when the vessel is not in motion. It is often desirable to have a vacuum in the condenser before the engines start so that it will assist in starting. For this reason a condenser is sometimes used like that shown in Fig. 36. This condenser is of the surface type, the chief difference being in the pumps. The air-pump is independent of the main engine. The steam piston, the air-pump piston, and the circulating-pump piston are all on one rod. Thus the pumps may be started and a vacuum formed before the main engines are started.

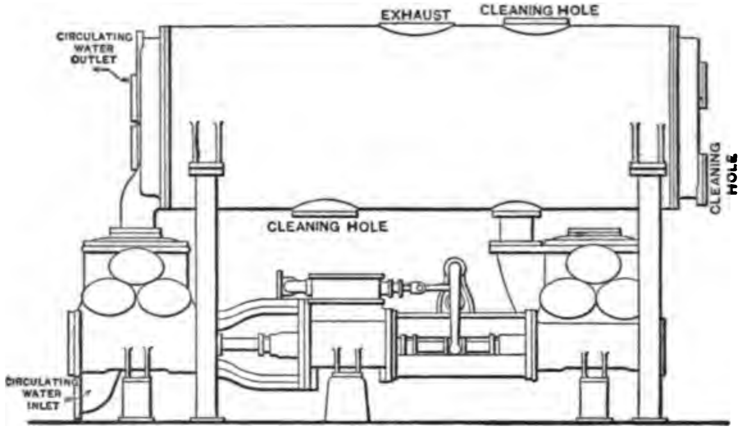


Fig. 36.

A vacuum may be formed by admitting live steam to the condenser and then forcing in the circulating water. The live steam drives the air out of the snifting valve when the pressure in the condenser exceeds atmospheric pressure. The snifting

valve is a small check valve attached to a condenser; the pressure of the atmosphere keeps it closed. When live steam is admitted to the condenser, the pressure will become greater than atmospheric pressure and the air is driven out of the snifting valve. When the circulating water condenses the steam the pressure within the condenser decreases, because water occupies much less volume than the same weight of steam and the valve closes. In case there is no snifting valve, the drain cock may be used in its place, but it is not automatic.

On account of the oil in the exhaust steam, the condenser tubes become covered with a coating of grease and have to be boiled out. To do this the condenser is nearly filled with a solution of hot water and caustic soda; live steam is then taken from an auxiliary or donkey boiler.

In order to have the vacuum maintained the air must be exhausted from the condenser continuously. This is done by the air-pump which withdraws the condensed steam, any air that may leak in and any vapors that may rise from the water.

The **air or vacuum pump** is made in a variety of constructions, a common form being shown in Fig. 37. It consists of a cylindrical cast-iron casing or barrel B. Sometimes a brass barrel or liner is fitted within the iron casing. The pump is bolted to the condenser in such a manner that the condensed steam will flow into the pump at E. The bucket or piston P fits the barrel closely and moves up and down within it. At the bottom of the pump several *foot valves* F are fitted. Similar valves A, called *delivery valves*, are fitted to the top of the pump. In the pump shown there are four bucket and four delivery valves. Also there are four similar valves H, in the piston.

The valves C are usually made of hard rubber. They are circular flat plates which seat on flat brass seats perforated to allow water and air to pass. The valves are placed on studs on which are guards *a*, which limit the rise of the valves.

Sometimes a light brass spring is placed between the guard and the valve to help return the valve to the seat. It is seldom that these springs are placed on the foot valves but they are frequently found in the bucket and delivery valves. As the spring tends to keep the valve to its seat, more force is required to open the valve when a spring is used. Hence, if springs are fitted to the foot valves they may cause an imperfect vacuum since the force which opens them is the hydrostatic head and the air pressure in the condenser.

The action of the pump is as follows: When the piston descends, as shown by the arrow, the foot and delivery valves close and the bucket valves open. The water and air above the foot valves enter the space above the piston. When the piston rises, the bucket valves close because of the pressure of water on them. The water is therefore carried up by the piston and forced through the delivery valves. While the piston is rising a vacuum or partial vacuum is formed below the piston, and the pressure of water and air in E causes the foot valves to open and the water and air rushes through to fill the space under the piston. When the piston has reached the top of the pump the space below it is filled with water and air, and the water and air above it are being discharged to the hot well through N. When the piston commences the down stroke the delivery valves close and prevent the air and water from returning to the air-pump, the bucket valves open to admit a new supply to the top of the piston and the foot valves close.

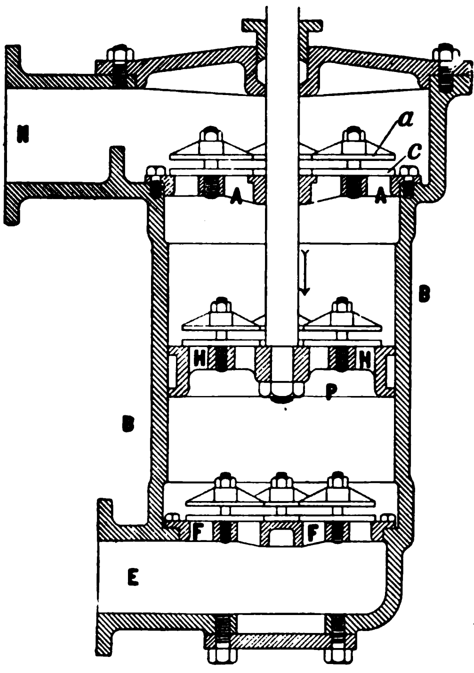


Fig. 37.

Foot valves are not absolutely necessary, in fact they are sometimes omitted but their use increases the reliability of the pump.

A small check valve or pet cock is generally fitted to the pump below the delivery valves. It is used for admitting air above the piston to prevent slamming of the pump. If there is no air cushion, the shock of the water on the up stroke is likely to cause slamming. When slamming occurs it may be stopped by admitting more air. This air does not effect the vacuum because it does not flow through the bucket valves. In Fig. 37 all the valves are shown down on their seats.

The vacuum that can be obtained depends upon the lightness of the valves, and the thoroughness with which the pressure is removed from above the foot valves by the air-pump. This in turn depends upon the nearness of the bucket to the foot and delivery valves at the ends of the stroke and the fit of the piston.

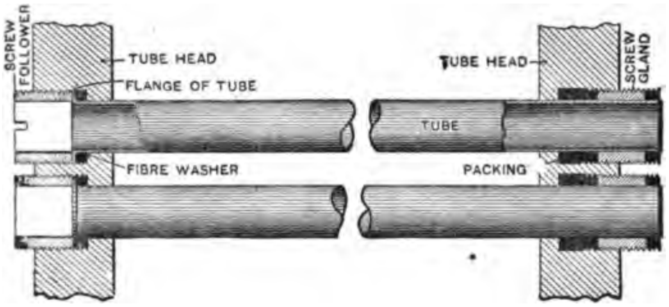


Fig. 38.

Details. The condenser is usually formed of a large number of solid drawn brass tubes $\frac{5}{8}$ or $\frac{3}{4}$ inch in diameter and about $\frac{1}{20}$ inch thick. The reason why they can be made so thin is because there is no pressure on them other than atmospheric pressure. These tubes are arranged zig-zag or staggered, between two end plates which may be circular, oval or rectangular. The entire condenser is often made of brass to prevent waste by galvanic action. The tubes must be fitted water-tight in the tube plates and at the same time free to lengthen and shorten under changes of temperature. For this reason they cannot be expanded in place like boiler tubes. They are fitted with a stuffing box at each end as shown in Figs. 38 and 39. The hole in the plate is slightly larger than the tube. The large part of the hole is provided with threads to receive a small gland or ferrule which compresses a ring of packing or a washer of fibre. It is of great importance that the condenser tubes should be tight for if leakage occurs, salt water will enter the feed water and coat the tubes of the boiler with salt.

It sometimes happens that the circulating-pump breaks down and the condenser cannot be run as a surface condenser. When this happens a pipe may be rigged so that the exhaust will go out of the engine room to the deck. The engines will then run non-condensing and will of course develop less power on account of the greater back pressure. Another method is to run jet condensing. This may be done by having the condenser piped so that the sea water will enter the top of the condenser and mingle with the exhaust steam by means of a perforated spray pipe within the condenser.

As the amount of water used for circulating water is greatly in excess of the amount used in the boilers, the air-pump removes a much larger quantity of water than can be used by the boilers. A part of the water from the condenser if running jet condensing goes to the hot well and is taken by the feed pumps, the remainder goes overboard.

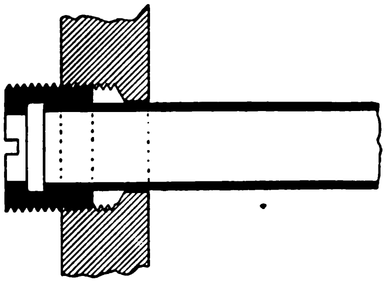


Fig. 39.

In running jet condensing, the water that is fed to the boilers contains considerable salt since the injection water is sea-water and the exhaust steam mingles with it and goes to the air-pump. For this reason, jet condensing is used only in case of emergency. For lake and river steamers, however, the jet condenser is frequently used, especially for low pressure, because it is cheaper and requires less injection water.

In case no arrangements are made for running the surface condenser as a jet condenser, a few tubes removed from the surface condenser will allow the injection water to mingle with the exhaust steam. Enough tubes should be removed to equal the area of the main injection pipe. In the surface condenser the space in which the condensation takes place is not in communication with the atmosphere. But the space occupied by the injection water communicates with the atmosphere by the discharge pipe if the discharge is above the water line. Hence when the surface condenser is changed to a jet, the valve in the delivery pipe must be closed to prevent the air from entering the condenser and thus destroying the vacuum.

The **vacuum** in the condenser is measured by a vacuum gage which is similar to a pressure gage. The pressure gage measures pressure in pounds per square inch but the vacuum gage is graduated to correspond to the barometric column; that is, in inches of mercury. A perfect vacuum represents about 30 inches of mercury and if there is atmospheric pressure in the condenser the pointer would stand at zero.

Since the pressure of the atmosphere is about 15 pounds per square inch and the mercury column is 30 inches high for atmospheric pressure, an inch of vacuum represents about $\frac{30}{15} = \frac{1}{2}$ pound pressure. Thus 10 inches of vacuum means that there is a vacuum corresponding to $10 \times \frac{1}{2} = 5$ pounds pressure. Or the 10 inches of vacuum means that 5 pounds of pressure have been removed from the condenser and $15 - 5 = 10$ pounds pressure remains.

Suppose the needle stands at 26. Then the pressure that has been removed equals 26 inches of mercury which equals 13 pounds. If 13 pounds have been removed the actual pressure in the condenser is $15 - 13 = 2$ pounds. Another way would be to subtract 26 from 30 and divide by 2. Thus, $30 - 26 = 4$ and 4 divided by 2 equals 2.

In case great accuracy is required, one inch of vacuum is taken to be .49 pound instead of .5 or $\frac{1}{2}$ pound. Thus, 22 inches of mercury indicates a pressure in the condenser of 3.92 pounds, for $22 \times .49 = 10.78$ and (atmospheric pressure) $14.7 - 10.78 = 3.92$; or $30 - 22 = 8$ and $8 \times .49 = 3.92$.

Amount of vacuum. In the study of the properties of steam, it was shown that there was a definite relation between the pressure and temperature of saturated steam. Thus if the pressure in the condenser is known, the temperature of the condensed steam can be readily found by referring to steam tables. This temperature decreases as the pressure decreases. Thus if an almost perfect vacuum is carried, there will be very slight pressure in the condenser and the temperature of the water removed will be low because the temperature given in the steam tables is the maximum temperature obtainable. On account of the heat lost by radiation and the difficulty of regulating exactly the amount of injection water, the temperature is a little lower than that given in the steam tables.

Suppose the pointer stands at 26. The pressure in the condenser is 30 — 26 = 4 and 4 × .5 = 2 pounds. The temperature is then about 126 degrees. If less water is circulated, and the pointer stands at 20 inches the pressure is 30 — 20 = 10 and 10 × .5 = 5 pounds; the corresponding temperature is then about 162 degrees. Thus a difference of 6 inches in the vacuum makes a difference of 36 degrees. Then this question arises: Shall we carry a good vacuum and thus increase the power of the engine and feed water to the boilers at (theoretically) about 126 degrees or shall we have a little greater back pressure (5 pounds) and feed water 36 degrees warmer? This question must be answered by the engineer in charge and as to which is the more economical can often be determined only by a test.

With the surface condensers, the vacuum usually carried is from 22 to 26 inches and with jet condensers 20 to 24 inches is common.

If the temperature of the hot well is to be high, a low vacuum must be carried in the condenser. To lower the vacuum decrease the amount of circulating water.

Imperfect vacuum. If the pointer of the vacuum gage stands less than 30 it means that the vacuum is not perfect or it is "low" as it is turned. We have already considered the results of a low vacuum. It may be caused by too little condensing water, air-pump out of order or the piston not coming close to the foot and delivery valves or by air leaks.

If the vacuum is low, and an increase in the amount of circulating water fails to increase it, but lowers the temperature of the hot well, it indicates that the exhaust is cooled to a low temperature and consequent low pressure. This state of affairs indicates an air leak about the engine or condenser. If a lighted candle is passed around the joints, the flame will be drawn toward the leak since the pressure outside is greater than the pressure inside, and the inrush of air would cause the flame to be drawn along with the current. A little red-lead putty applied to the crack will usually stop the leak.

If the fault is not in the condenser or in the amount of circulating water, probably the air-pump is out of order. A broken or hung-up valve often causes an imperfect vacuum.

The Keel Condenser. Steam launches for fresh water frequently have no condenser but use high-pressure steam and draw the feed water from the lake or river. For salt water, however, it is desirable to use the feed water over and over again on account of the boilers. In many launches, an ordinary surface condenser would take up considerable room and be an extra weight.

For such cases a brass or copper tube, or several tubes, are placed outside of the hull along the keel. The exhaust from the engine enters at one end, is condensed by the cold water, and drawn out of the other end by the air-pump. This is a very simple arrangement since no circulating arrangements are needed. The passing of the hull through the water takes the place of the circulating-pumps.

Feed Tanks. The air-pump of the condenser discharges into a feed tank which holds the feed water that is not immediately needed for the boilers. This tank is usually made large enough to contain all the discharge from the air-pump for four or five minutes when running at full power. From this tank the water is pumped into the boilers as needed. In some ships the air-pump discharges into the hot well, and is then either pumped directly to the boilers or is carried to a feed tank. A feed tank is usually fitted to each engine room.

The tank is provided with two overflow pipes ; one leading to the reserve tank, and the other to the bilges. In case oily matter collects on the surface of the water in the feed tank, it can be discharged into the bilges by the overflow. The feed tank should have an arrangement for the escape of air, and should be provided with fittings to prevent grease from entering the reserve tanks or the feed pumps.

It is very important that feed water should contain as little grease as possible. For this reason some vessels are fitted with a tank, pump and grease filter between the air-pump and feed tank. It is a good plan to filter the water before it enters the feed pumps rather than to filter it while going from the feed pumps to the boilers. If a grease filter were placed between the air-pump and feed tank it would bring a great strain on the air pump. To prevent this the air-pump is made to discharge into the hot well from which the water is drawn by a pump called the hot well pump. This pump takes water from the hot well and forces it through the filter to the feed tank. A by-pass or escape valve is fitted so that when the filter becomes clogged or the hot well pump gives out the water will flow directly to the feed tank.

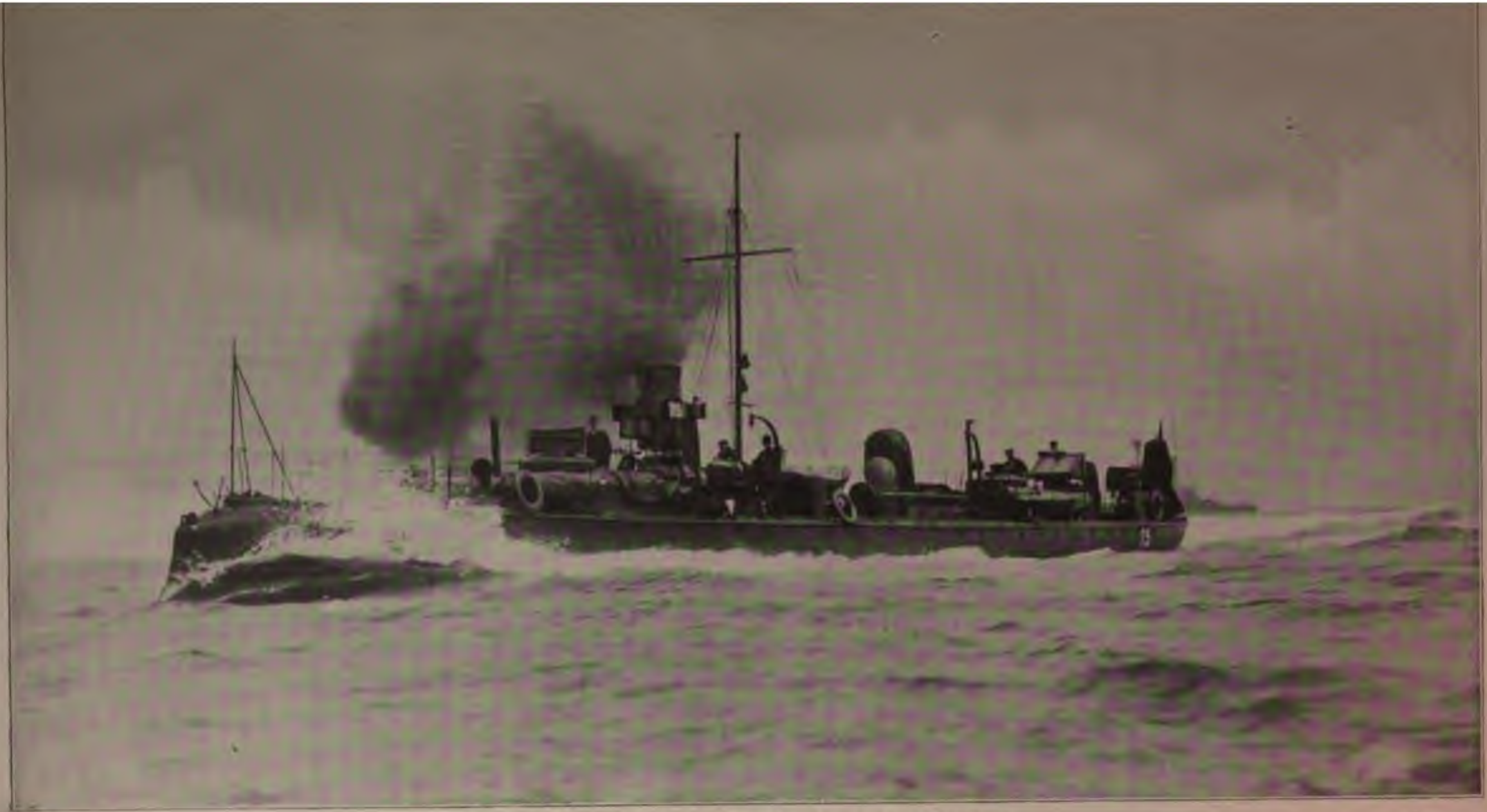
The *reserve tanks* are tanks placed in the double bottoms under the engine or boiler rooms for carrying a reserve supply of fresh water. They are fitted with valves and pipes, so that they can receive water from the feed tanks and from the boilers. Also, so that water can be drawn from them as required. On ships having evaporators and distillers, the reserve tanks need not be as large because it is not necessary to carry as large a quantity of fresh water.

Feed-Pumps. The feed water is taken from the bottom of the feed tanks or from the hot wells and pumped into the boilers. The pumps for this work are almost always of the independent, direct-acting type. They usually take steam from the main steam pipe and the auxiliary pumps from the auxiliary steam pipes. It is a good plan to place the main pumps in the engine rooms and the auxiliary pumps in the boiler rooms. The main pumps are piped to the feed tanks or hot wells, and can pump to all of the boilers. The auxiliary pumps draw from the feed tanks and from the auxiliary condensers, and are also piped to pump from the reserve tanks and from the sea.

Arrangements for Reducing Waste. In order to make the amount of make-up water as small as possible, there are fitted several devices for reducing waste.

Formerly all of the auxiliary engines, such as those for steering, circulating-pumps, hoisting, electric-lighting, etc., exhausted into the atmosphere. To prevent this waste, they are made to exhaust into **auxiliary condensers** which are like the main condensers in construction, arrangement and fittings. The air-pumps for these condensers, called the auxiliary air-pumps, discharge into the feed tanks.

In case the engines are eased or stopped, the **safety valves** are likely to blow off until the fires and draft can be regulated. The



BRITISH FIRST-CLASS TORPEDO-BOAT AT FULL SPEED.

Tearing through the sea with red-hot funnel at nearly forty miles an hour, that she may get near a battleship and discharge one of her Whitehead torpedoes.

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steam that escapes is usually led to the main condensers and there condensed. Since the air-pump (if it is not independent) stops when the main engines stop, provision is made by means of a suction pipe, for keeping the vacuum in the main condenser by running the auxiliary air-pump which is independent.

At the present time, with surface condensers, evaporators, etc., the boilers need be **blown out** only at long intervals. After the boilers have been at work for a considerable length of time, the surface of the water becomes dirty and the surface blow must be used, but this does not happen frequently, and as the boilers are blown out but seldom, the loss from this cause is slight.

The **drains** from the main engines are usually connected to the main or auxiliary condensers, or with a drain pipe leading to a drain tank, thus greatly decreasing the waste from this cause. In case the drainage water from the auxiliary cylinders is very greasy, it must be filtered or discharged overboard.

Formerly it was the custom to fit small hot wells; this caused frequent discharges to the bilge or overboard. To reduce loss, the hot wells are either made larger or feed tanks are used having overflows to the reserve tanks.

In spite of all the precautions taken to reduce the waste of fresh water, considerable make-up water must be provided. This is usually from three to eight per cent. of the total water used, depending upon the condition of the machinery, etc. This make-up water may be taken from the sea or from evaporators. For vessels making short trips, fresh water may be carried and evaporators dispensed with. Distilling arrangements were discussed in "Marine Boilers."

Thus far we have considered the working fluid (water and steam) in the various parts of the machinery. Now let us trace its course in the boilers and engines by means of a brief summary.

Boilers to Engines.	Steam space, internal steam pipe, stop valve to main steam pipe. Then through bulkhead stop valves (if fitted) to regulating valve, to steam chest of high-pressure cylinder.
Through H. P. Cylinder.	From steam chest of high-pressure cylinder through the ports to the cylinder. After doing work, through the exhaust ports to the first receiver, and then to steam chest of the intermediate cylinder.

Through I. P. Cylinder.	From the steam chest through the ports to the cylinder. After expanding, through the passages and exhaust cavity to the second receiver, and then to the steam chest of the low-pressure cylinder.
Through L. P. Cylinder.	From the steam chest, through the ports to the low-pressure cylinder. After the expansion is completed, through the exhaust passages to the exhaust pipe, to the condenser.
Condenser to Feed Tanks.	The exhaust steam enters the condenser, is condensed, falls to the bottom of condenser. Through foot, bucket and delivery valves of the air pump to the discharge pipe, to hot well or feed tanks.
Feed Tank to Boiler.	From the feed tank to the feed pump suction pipe, through the suction and delivery valves, to the feed pipe. Through feed valve to internal feed pipe.

The water, entering by means of the internal feed pipe, is evaporated in the boiler, rises to the steam space and commences the circuit again.

AUXILIARY MACHINERY.

In modern steam vessels, especially if they are large or in war-vessels, the auxiliary machinery is of great importance. Some vessels have more than 100 different auxiliary engines, some steam, others hydraulic and some run by compressed air and electricity. In battleships there are many engines used for working turrets, loading, training and working guns. Compressed air is not used as extensively as steam, water and electricity, but it is often used for discharging torpedoes.

The large number of auxiliary engines makes it impossible to describe them here; among the most important uses in addition to propulsion are ventilation, forced draft, feeding boilers, weighing anchor, steering, electric-lighting, refrigerating, lifting coal, discharging ashes, etc.

The transmission of power and electric signalling on board ship have become of first importance. Wires can be conducted in places where the placing of steam pipes would be almost impossible.

The steam engines used for auxiliary purposes act upon the same principal as the main engines. Vertical engines are fre-
used because of the saving in floor space. The pumps
boilers, the engines for the circulating pumps, etc.,

being vertical in most instances. As before mentioned, the auxiliary engines exhaust into the auxiliary condenser both because of economy and on account of the feed water.

PROPULSION.

In order to move a ship the resistance must be overcome. When the engines are started, the paddle wheels or screw revolve for a short time before there is any appreciable headway. The power of the engine has, during this time, been expended in overcoming the inertia of the ship. When the inertia has been overcome the power is utilized in overcoming the resistance of the water and air and in increasing the speed of the ship. As the speed increases the resistance increases, and there comes a time when all the power is used for overcoming the resistance and there is none left for increasing the speed. The ship then moves along at an approximately constant speed.

The resistance offered to a ship's motion in smooth water may be divided into three elements:

Frictional resistance of the skin.

Eddy making resistance.

Wave making resistance.

Frictional resistance is by far the most important. The amount of friction between the immersed skin and the water depends upon the area and length of the immersed surface, upon the roughness and upon the speed. As a foul bottom causes a considerable increase in resistance and consequent reduction in speed, the ship's bottom and the propeller blades should be kept as clean as possible.

Eddy making resistance is usually small. It is caused by the form of the stern and by the churning of the propeller.

The amount of resistance due to **wave making** depends upon the form of the ship. At the bows of all ships some waves are formed, and if they pass away from the ship without producing a corresponding reaction under the stern the energy used in forming the waves is wasted.

Wind and waves also cause the resistance to be increased, but the resistance from these causes is difficult to estimate. The larger and longer a ship, the less the wind and waves affect its progress. This is shown by the regularity with which large ocean steamships make their voyages under varying conditions of wind and sea.

Experiment shows that within ordinary limits the resistance varies as the square of the speed, and the power required to overcome the resistance varies as the cube of the speed. In other words, if a ship has a certain resistance at a given speed the resistance will be four times as much if the speed is doubled; and the necessary power will be eight times as much.

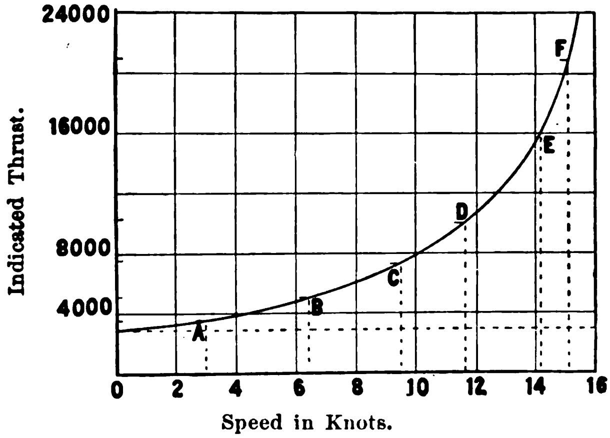

Fig. 40.

By considering the above law and the various resistances, there have been produced many formulas for finding the power necessary for a given speed. These formulas are of little value, however, unless the designer knows all the data of ships of similar form, size and speed.

The indicated horse-power is not a true measure of the work done by the propeller, because of the efficiency of the machinery and of lines of the ship.

Indicated thrust. The indicated thrust is a mathematical expression very commonly used in connection with propulsion. Its name is derived from indicated horse-power and is expressed in pounds. A horse-power is 33,000 foot pounds per minute, and hence the total work in foot pounds done by the engine is equal to I.H.P. × 33,000. This total work done divided by the distance through which it acts in one minute is the indicated thrust.

Let I.H.P. = indicated horse-power of the engine.
p = pitch of the screw in feet.
N = number of revolutions per minute.
T = indicated thrust.

$$T = \frac{33{,}000 \times \text{I.H.P.}}{pN}$$

$$\text{Since I.H.P.} = \frac{2PLAN}{33{,}000}$$

$$T = \frac{2PLA}{p}$$

Suppose a marine engine develops 1,200 I.H.P. when making 90 revolutions per minute. If the pitch of the propeller is 20 feet, what is the indicated thrust?

$$T = \frac{33{,}000 \times \text{I.H.P.}}{pN}$$

$$= \frac{33{,}000 \times 1{,}200}{20 \times 90}$$

$$= 22{,}000 \text{ pounds.}$$

By calculating the indicated thrust from the horse-power for given speeds, a curve may be drawn which will show the thrust for all speeds. Such a curve is shown in Fig. 40. The vertical components or ordinates are indicated thrusts in pounds and the horizontal components or abscissæ are speeds in knots.

The most economical speed is the speed at which the ship can steam a given distance with the least consumption of fuel. Or, it is the speed at which the coal burned per knot is least. In general, if the speed is reduced the expenditure of coal is reduced. However, the reduction continues only until a certain speed is reached, after which the coal consumption rises as the speed diminishes. There is no way to calculate the speed at which this change occurs; it can be found by trial only. The ship is run at various speeds and the engines carefully tested. The most economical speed then can be found by dividing the coal consumption per hour by the speed in knots. The lowest value shows the most economical speed.

It is practically impossible, or at least inconvenient, to make the trials at all speeds. To obviate this difficulty, the results are plotted graphically, as shown in Fig. 41. The consumption of coal per day in tons is plotted as the ordinates and the corresponding speed in knots as the abscissæ. If a straight line is drawn from O, tangent to the curve, the speed corresponding to the point of tangency will be the most economical speed. Thus for the conditions represented in Fig. 41, the most economical speed is a little less than 8 knots because O N is tangent to the curve H K at N. The Coal consumption is, from the diagram, about 9 tons per day. The curve shows that the machinery works economically between 6 and 10 knots as the line O N lies near the curve for those speeds. If, however, the speed falls below 6 knots or rises above 10 knots the coal consumption increases rapidly.

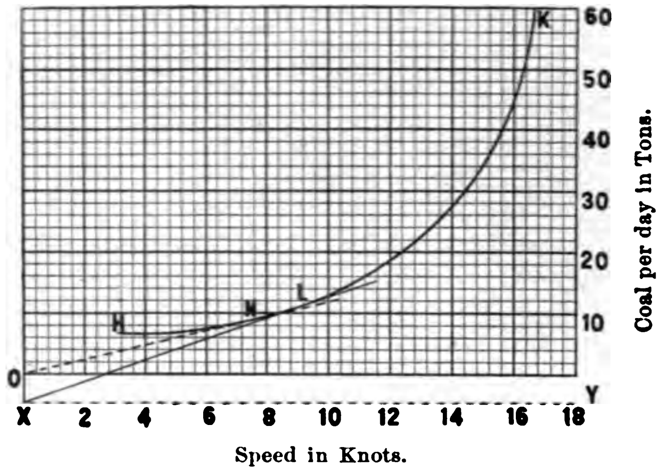

Fig. 41.

The curve thus drawn is for the propelling machinery only. If the most economical speed, including auxiliary machinery, is to be determined, the distance O X is set off below O to represent the coal used for auxiliary purposes. The tangent X L is then drawn as before. This tangent shows the most economical speed to be about 8½ knots.

PROPELLERS.

Of the three methods of propelling ships by steam, the propeller is by far the most important.

Jet propulsion is so uncommon that it requires no discussion. Paddle wheels are used for river and harbor boats, especially in shallow water. For sea-going vessels, lake steamers and steam yachts the screw propeller is almost universally adopted. It is taking the place of the paddle wheel even in its own territory. For war-ships the screw is especially desirable, as with it all the machinery, including the propeller itself, can be placed below the water line.

A **screw propeller** is a set of blades, usually of iron, bronze or steel, placed on a horizontal shaft and made to revolve by means of the engine.

Material. For small vessels, the screw propeller is often made of cast iron on account of cheapness. The blades, and boss or hub, form a single casting. If the propeller is large, the blades are made separate and bolted to the boss. This method has several advantages; the difficulty of manufacture is not as great, the whole propeller is not disabled in case one blade is broken, it is much more easily handled and the boss and blades may be of different material. With a propeller having detachable blades, extra blades are carried so that the propeller may be repaired in case of accident. Cast steel is used to some extent, but although the blades can thus be made thin (thereby increasing the efficiency) they are liable to corrosion. Bronze and gun-metal are perhaps the best materials, as they are strong, tough and resist corrosion. Sometimes the blades are made of bronze and the boss of cast iron.

Shape of the blades. Each blade may be considered as a small part of the thread of a screw of great pitch and depth. The simple screw first consisted of a part of a true helix cut off by two parallel planes perpendicular to the axis. By making a double helix, or double threaded screw, two blades were obtained. After a time the forward edges were cut away to reduce vibration and the blade gradually assumed the shape of the present time. The form of each blade may be conceived by imagining a straight line revolving around another straight line perpendicular to it and traveling along the line while it revolves.

The acting surface or front of the blade is the after face and the true screw surface, but the back or forward face has not the true screw surface on account of the thickness necessary for strength. The best shape for screw propeller blades is largely a matter of experiment. The form is practically elliptical and the transverse sections approximate semi-ellipses.

It is remarkable that small changes in form often make a great difference in speed and power.

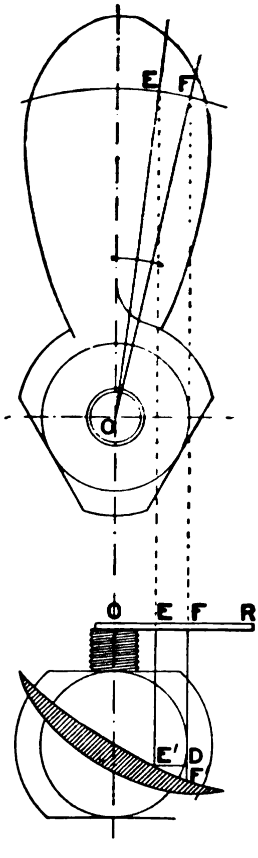

Fig. 42.

Number of blades. Propellers are made with two, three and four blades. For smooth water the two-bladed propeller is efficient; for rough water, when the boat pitches, three or four blades are more satisfactory. Three or four blades are the more common, as they have continuous action. Four is the most common for the merchant marine. If four blades are used and one becomes broken, the three remaining blades are sufficient, but if the propeller has but two blades and one of them is broken, the propeller, having but a single blade, is so badly balanced that the engines are severely strained.

Pitch of screw. The pitch of a screw propeller is the distance that a point on a blade travels in the direction of the axis during one revolution. It is the distance that the propeller will advance during one revolution provided there is no slip. A screw propeller is very similar to an ordinary wood or machine screw of coarse pitch. In the case of a wood screw or cork screw, the screw advances a distance equal to the pitch during every revolution.

The pitch is often uniform, that is, the pitch is the same for points on the blades. Sometimes the pitch is increased htly toward the tips of the blades so that shock will be re-ing the action more gradual.

of pitch. If a propeller is made in one solid way to alter the pitch. With most propellers the blades are detachable, that is, they are made separate and bolted to the boss. The holes in the blade flanges of large propellers are made elongated so that the position of the blades may be altered slightly, thus changing the pitch. The allowable change in pitch is not greater than three or four feet even in large wheels.

The *pitch ratio* is the ratio of the pitch to the diameter. Suppose a screw propeller is 16 feet in diameter and has a pitch of 21 feet, the pitch ratio is $\frac{21}{16} = 1.31$.

To find the pitch. From the definition it is evident that to find the pitch of a propeller it is necessary to know how far a point moves in a line parallel to the axis while it moves through a known angle. These two measurements may be found as follows:

The tail-piece and cap-nut are first removed and a wooden bar of sufficient stiffness is fixed to the end of the shaft as shown in Fig. 42. The center of the bar should coincide with the center of the shaft and be made so that it can move about the point O in a plane perpendicular to the axis of the shaft. In the lower portion of Fig. 42, O R represents the radius bar, and in the upper portion O E and O F represent the center lines of O R.

First, place O R in some position, O E for example. Then measure by means of a rod or in some other manner the perpendicular distance from E to the blade. This will be E E′ in the lower portion of Fig. 42. Now move O R through a small arc as E F, and mark the angle E O F on the boss or measure it. Again measure the perpendicular distance from the bar to the blade which will be F F′. Subtracting E E′ from F F′ leaves D F′. Now, D F′ is parallel to the axis and is the distance that the given point E moves in that direction while it moves through the arc E F.

Suppose the angle E O F is $5\frac{5}{8}$ degrees or $\frac{1}{64}$ of 360°, $(360 \div 5\frac{5}{8} = 64)$ and D F′ is three inches. Then, while the point moves through $\frac{1}{64}$ of the circumference it moves 3 inches. In moving through the whole circumference it would move $3 \times 64 = 192$ inches $= 16$ feet in the direction of the axis. Hence the pitch is 16 feet. This may be expressed as a simple proportion, because E O F is the same fraction of the complete circumference as D F′ is of the pitch. Or,

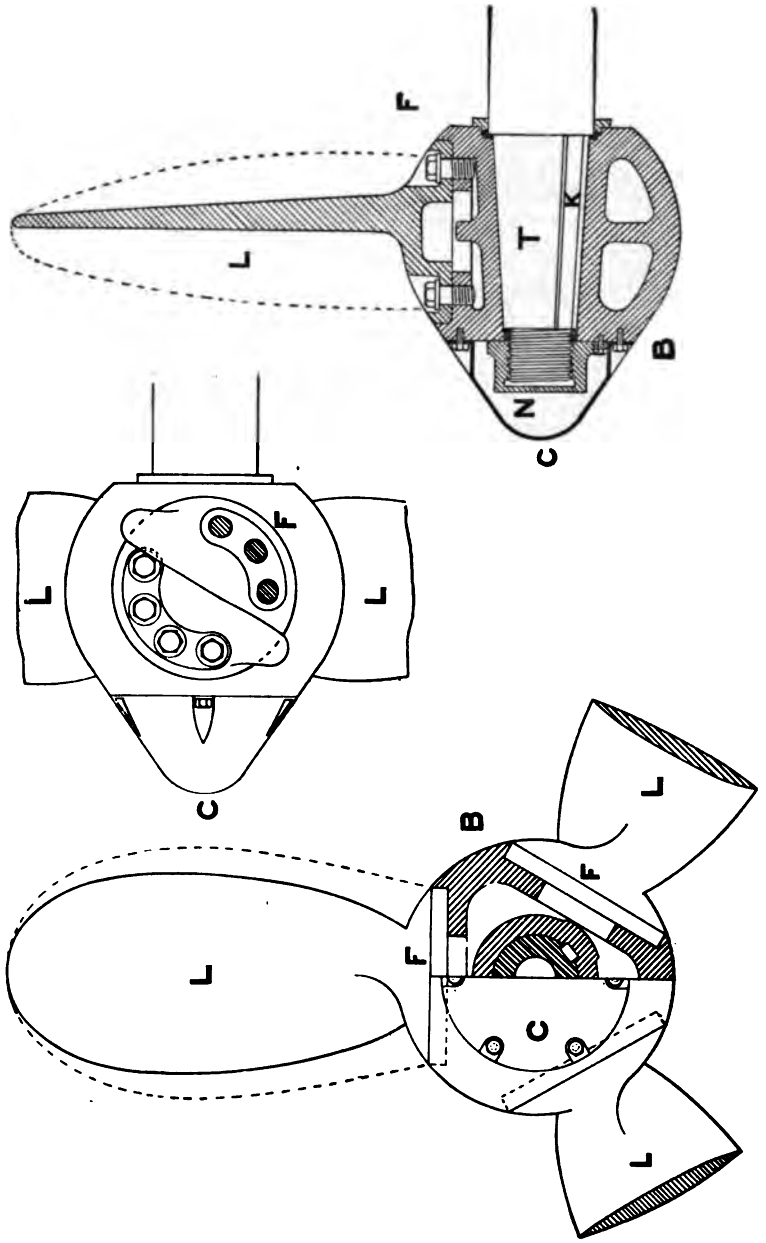

Fig. 43.

$$E\,O\,F : 360 :: D\,F' : \text{pitch}.$$

It may be more convenient to measure E F than to measure the angle. Then,

$$E\,F : 2\,\pi \times O\,E :: D\,F' : \text{pitch}.$$

This method assumes the pitch to be constant. If it is not constant and if it is desired to find the mean pitch, find the pitch in the manner described above for several points and then find the average pitch.

The Diameter of the Screw Propeller is the diameter of a circle described by the extreme end of the blades if the pitch is zero. As in the case of a wood screw the diameter is the outside diameter. The area of this circle is called the *disc area.*

Determination of Pitch and Diameter. There are many rules for determining the proper diameter and best pitch for propellers but they are of little value unless all the conditions are known and the conditions are similar to those in vessels already built. The diameter of the screw for a single screw steamer depends upon the amount of water the steamer draws aft. The screw is usually made large so that the pitch may be large and the engines run at moderate speed.

The pitch is determined from the diameter. The allowable range of pitch ratio is considerable; that is, there is no great change in efficiency for a slight change in pitch ratio. The best ratio seems to be between 1.1 and 1.5. Then for a wheel 14 feet in diameter, the pitch would probably be between 15 and 21 feet.

Details. A modern form of screw propeller is shown in Fig. 43. It consists of a boss B and three blades L which are bolted to it. The boss is made large, much larger than is necessary to fasten it to the shaft. The reason for making it large is that the portions of the blades near the boss are ineffective, that is, they simply churn the water without producing useful results. This churning is reduced by making the boss large. The boss is generally made spherical or pear-shaped so that it will offer little resistance while passing through the water. The hole through the boss and the portion of the shaft T which carries the propeller is tapered. A longitudinal key K, prevents the propeller from rotating on the shaft. The end of the shaft is threaded and the boss kept in place by the cap-nut N. This nut is secured by means of a keep-plate or other device.

A conical tail-piece C bolted to the end of the boss reduces eddying, prevents corrosion of the cap-nut and shaft and also prevents fouling by ropes. At the other end of the boss a stuffing-box prevents water from entering at the junction of the boss and shaft.

The flanges F of the blade are recessed into the boss and are bolted to it. The heads of the bolts are recessed into the flanges and covered with plates. By this means the spherical form is preserved.

Action of the Propeller. When a screw propeller is revolving in a given direction (for go-ahead motion for instance) the blades press on the water as the threads of an ordinary screw do upon the threads in the nut. The pressing of the blades on the water causes the water to be driven backward. The result of the reaction caused by projecting the mass of water sternward is the ahead motion of the boat. The useful work done by the propeller is that which forces the water directly sternward; the movement of water in any other direction is waste power.

Speed of the Screw. If the screw worked in an unyielding medium, it would advance a distance equal to its pitch at each revolution. Hence the speed of the screw per minute is the product of the pitch and the number of revolutions per minute.

Example. Suppose a screw is of 18 feet pitch and makes 72 revolutions per minute. What is the speed of the screw in feet per minute and knots per hour?

$$18 \times 72 = 1{,}296 \text{ feet per minute.}$$

$$1{,}296 \times 60 = 77{,}760 \text{ feet per hour.}$$

$$\frac{77{,}760}{6{,}080} = 12.78 \text{ knots per hour.}$$

However the water is a yielding medium and for this reason the pressure of the blades causes the water acted on to be driven back instead of remaining firm. Then the actual speed of the ship (when referred to the undisturbed water at a slight distance from the ship) is less than the speed of the screw. This difference is called slip.

Slip is the difference between the speed of the screw and the speed of the ship, relative to still water. It is expressed in feet per minute and as a per cent. of the speed of the screw.

Example. A ship is moving at the rate of 16 knots per hour. The screw has a pitch of 19 feet and makes 97 revolutions per minute. What is the slip?

$$19 \times 97 = 1{,}843 \text{ feet per minute} = \text{speed of screw.}$$

$$\frac{16 \times 6{,}080}{60} = 1{,}621 \text{ feet per minute} = \text{speed of ship.}$$

$$\text{Slip} = 1{,}843 - 1{,}621 = 222 \text{ feet per minute.}$$

$$= \frac{222}{1{,}843} = .1204 = 12.04 \text{ per cent.}$$

This may be expressed algebraically as follows:

Let S = speed of screw

s = speed of ship

L = slip in feet per minute.

Then

$$L = S - s$$

$$\frac{S - s}{S} \times 100 = \text{slip expressed in per cent.}$$

The slip thus found is not the *actual* slip but the *apparent* slip. It is not the actual or real slip because the screw does not act in still water but in water that has been set in motion by the screw itself or by the hull.

While the hull moves through the water, it sets in motion the water in contact with it; the direction being the same as that of the ship. The water close to the ship has a greater forward velocity than that at a distance. Since this water has a velocity a little less than that of the ship it soon falls behind the hull and is found at the stern. Thus the water in which the propeller acts has a forward velocity. Also the velocity is influenced by the waves and eddies due to the lines of the vessel. On account of the many conditions that make the velocity of the wake variable, it is difficult to calculate it.

When the propeller is considered it is evident that the condition of the water in which it works should be considered. Since the velocity is difficult to obtain, the real slip is not easily found.

When slip is referred to it is generally the apparent slip that is intended and not the real slip.

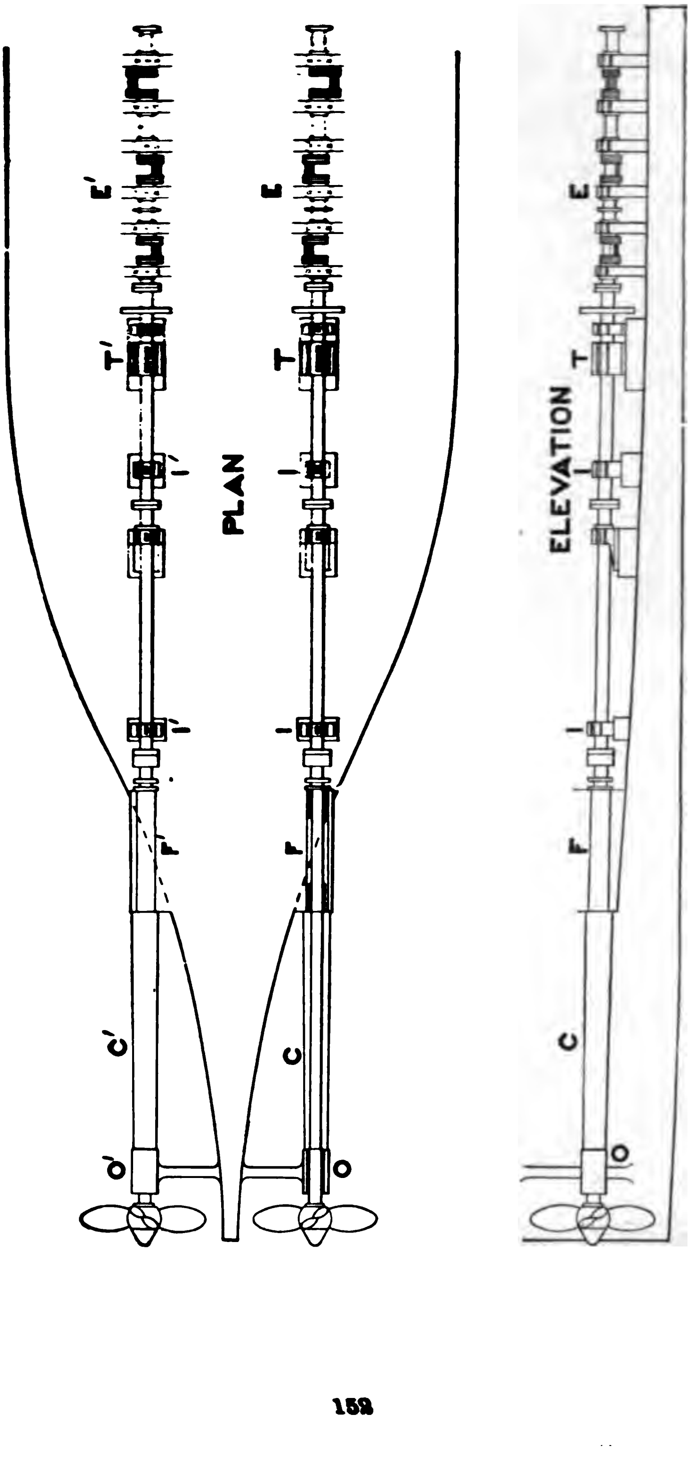

Fig. 44.

Apparent slip varies from 5 to 25 per cent., 15 to 20 being a fair average. The real slip is usually from 5 to 15 per cent. greater than the apparent.

Negative Slip. On account of the condition of the wake in which the propeller works, positive real slip is necessary. In some cases, the calculation has shown the apparent slip to be negative. This shows that the speed of the ship is greater than that of the propeller. If the real slip were small, 8 or 10 per cent. for instance, the apparent slip would probably be negative. There may be several reasons for negative slip, the most common one being the initial velocity of the wake.

Experiments show that with small percentage of real slip, the efficiency is low; hence if the apparent slip is negative or zero, it is generally considered that the propeller is not working efficiently.

In order to propel a large ship at a given speed the propeller must be large ; sometimes the ship draws too little water for such a propeller. Also, there are other conditions which sometimes make it desirable to use two propellers instead of one.

Twin-screws. Twin-screws are now common both in the navy and in the merchant marine. For twin-screws there are two separate engines, two shafts and two screws. These are placed on either side of the keel as shown in Fig. 44, which gives the arrangement of the shafting and bearings of a twin-screw ship. The bearings and cranks of the triple expansion engines are shown at E and E′. The shafting consists of the crank shafts of the engines and the screw shafts or propeller shafts which run aft from the engines to the screws. The shafting is made in convenient lengths and coupled together. The shafts are kept in place by means of bearings; main bearings at the engine, and screw-shaft bearings for the propeller shaft. The latter named bearings include the thrust blocks T and T′, the ordinary inboard bearings I and I′, the stern tubes F and F′ and the outboard bearings O and O′. The stern tubes are fitted where the shafts pass through the hull. The propeller shafts are enclosed in the casings C and C′ which extend from the stern tubes to the outboard bearings which are supported on brackets.

The shafting for large steamers is hollow, the internal diameter being about one-half the external. A slight addition to the diameter makes the hollow shaft as strong as the solid.

Twin-screws have the following advantages:

There being two screws, each may be of much less diameter, hence they may be run at greater speed, and for a given power the engines may be of shorter stroke. As the height of a vertical engine depends upon the length of stroke, engines for twin-screws need not be as high as the engine for a single screw.

The engines for twin-screws can be small as the necessary power for propulsion is divided; this is an advantage in manufacture.

With two engines, a bulkhead may be placed between them, thus forming two water-tight compartments.

If one engine is disabled the ship can be brought into port by the other.

With two screws the vessel can be turned more easily by going ahead with one and astern with the other. Also it can be steered to some extent by means of the two screws.

Triple Screws are used in very large vessels and in the navy. The triple screws give much the same advantages as twin screws. In the navy the center screw can be used for cruising, two for moderate speeds and all three for full speed.

ENGINE ROOM FITTINGS.

CYLINDER RELIEF VALVES.

It frequently happens that water collects in the cylinders because of condensation or priming of the boilers. If this water remains in the cylinder, it is likely to cause excessive strains or may even cause the cylinder heads to be blown off. To prevent accident, relief valves are often fitted to both ends of the cylinders. These valves are usually small spring-loaded safety valves as shown in Fig. 45. The springs are long so that the valves may have considerable lift without compressing the spring too much. They are set to open at about fifteen or twenty pounds above the initial working pressure.

Cylinder relief valves should be fitted to both ends of the cylinders of the main engines, although they are frequently

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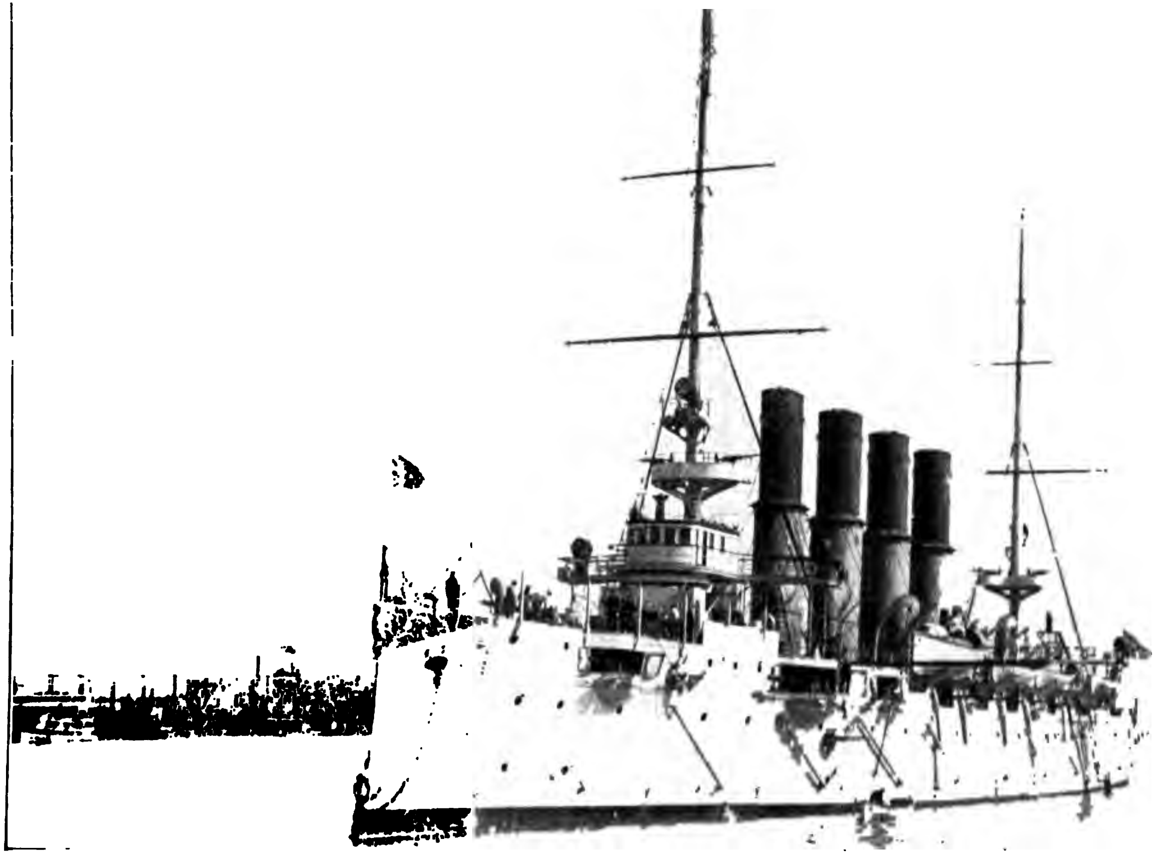


RUSSIAN CRUISER "VARIAG," BUILT AT THE CRAMP SHIP YARDS.

[illegible]

omitted from the top ends. These valves should be piped so that the hot water escaping from them will not scald those in attendance but will go to the condenser or the feed tank. Like other safety valves they should be provided with means for adjusting the tension of the springs and for locking them in position. Relief valves are also placed on feed pipes and the fire system to guard against split pipes in case the valves do not open.

DRAIN COCKS.

In addition to the cylinder relief valves, drain cocks are fitted to the lower ends of the cylinders. They should be fitted to any part of the engine where water is likely to collect, such as the cylinders, steam chest, jackets, etc. By means of these cocks, the cylinders may be drained while the engines are being warmed or while starting. They usually discharge into the condenser while under way or into the feed tank, thus saving the fresh water. The jacket drains often lead to a small vessel placed below the bottom of the cylinder and provided with a gage glass.

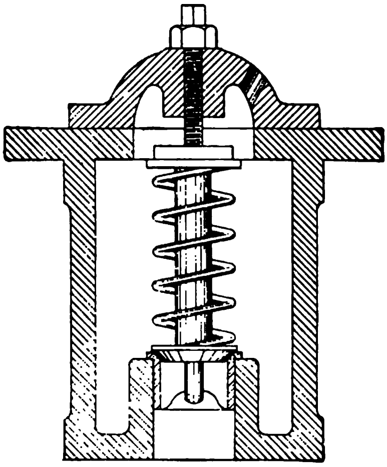


Fig. 45.

BY-PASS VALVES.

Compound, triple expansion and quadruple expansion engines are fitted with by-pass valves or auxiliary starting valves. **Auxiliary starting valves** are those which admit steam *directly* to the top and bottom of the cylinders without going through the receivers. This valve is a flat plate similar to a plain slide valve but without the exhaust cavity. It slides on a flat seat and the two ports communicate with the two ends of the cylinder. It is moved by means of a hand lever; if the lever is moved in one direction the valve admits steam to one end and when moved in the opposite direction steam is admitted to the other end. The levers are often arranged to move in the direction that the steam will move the piston. With these valves a triple expansion engine may be started if the valve of the high pressure cylinder covers both ports.

By means of the by-pass valves, live steam is admitted to the *receivers* so that the engines may be warmed before starting or easily started if both ports to the high pressure cylinder are closed, or if the high pressure crank is on dead center. As the steam is admitted to the receivers, it finds its way to the proper side of the pistons through the main valves. Thus it is not necessary to consider in which direction the piston is to move.

Starting by means of by-pass valves is slower than with auxiliary starting valves because the steam must first fill the receivers as well as the cylinder space on one side of the piston; also it increases the back pressure on the preceding piston, since that cylinder is in communication with the receiver by means of the exhaust cavity. The by-pass valves are often used, mainly because of their simplicity and the freedom from error.

RECEIVER SAFETY VALVES.

The receivers are sometimes constructed for a working pressure somewhat less than that of the high pressure cylinder. In starting, or in case the preceding valve were to get off its seat or should become broken, steam pressure is likely to accumulate in the receiver and exceed the allowable pressure. To relieve the pressure, small safety valves are fitted to the receivers. They discharge the steam into the engine room and so give warning of excessive pressure.

For an initial steam pressure of about 150 pounds, the safety valves on the intermediate and low pressure receivers should be set to blow at about 80 pounds and 30 pounds respectively.

The pressures in the receivers are shown by pressure gages. These gages are of the same form of construction as those used on the boilers, and are often piped so they may be seen from the starting platform.

JACKING GEAR.

In order that the engines may be turned over when not under steam, a large worm wheel is keyed on the after end of the crankshaft. In small engines, the jacking wheel may have holes or recesses in the rim so that it may be turned by means of a crowbar, or it may be turned by a ratchet and lever. For large engines, a small auxiliary steam engine is fitted on the frame to work the worm, so the engines may be turned rapidly in case of adjustment or repairs. When not under steam, the engines should be turned over daily to keep them in good condition.

The worm and worm wheel must be so arranged that when the engines are under steam the worm may be disconnected.

REDUCING VALVES.

The main boilers usually carry a steam pressure much higher than that used in the auxiliary engines. Although it is usual to supply auxiliary engines from auxiliary boilers or donkey boilers, yet it frequently happens that steam must be taken from the main steam pipe to run the steering-engine, electric-lighting engine, winches, etc. Also the pressure in the steam jackets is usually somewhat less than that of the boilers. To reduce automatically and maintain the pressure for these purposes, reducing valves are fitted. There are several forms of reducing valves used, the Foster valve as described in "Marine Boilers" being the most common.

Frequently a small safety valve is placed on the low pressure side for a relief in case the reducing valve gets out of order. Pressure gages are also fitted on the discharge side and sometimes on both sides. Reducing valves are especially desirable for dynamo engines or where high pressure water-tube boilers are used; if the pressure in the boilers varies, the reducing valve will keep it constant in the auxiliary engine for the close regulation necessary for electric lighting.

MAIN INJECTION VALVE.

The holes below the water line in the hulls of vessels must be fitted with valves to control the flow of water. In the case of the inlet for the condensing water for the circulating-pump, the **Kingston valve** was the one most commonly fitted. This valve is simply a conical valve opening outward so that the pressure of water keeps it closed. The valves are fitted with long spindles so that they may be opened and closed inside the ship. This form of valve was much used for wooden ships and is sometimes used for steel vessels. The ordinary screw-down valve is, however, frequently used in steel vessels as it is lighter and cheaper, and the Kingston valve has no especial advantage for such hulls.

The screw-down valves close against the pressure of water. In case of fracture, the sea-water will close the Kingston valve but will rush into the hull if the screw-down valve is used. Thus the former will automatically prevent the sinking of the ship. If the screw-down valve breaks, the inrush of sea-water may be reduced until repairs can be made, by passing a tarpaulin over the side and securing it over the opening.

The opening in the skin of the ship is provided with a strainer or grating of large area, to prevent sea-weed and other foreign matter from entering the pumps.

It is a good plan to fit a screw-down valve inside the ship near the sea-valve for additional security. This is especially desirable in case the main injection valve is a screw-down valve.

BILGE SUCTION.

As stated in discussing condensers, most vessels are piped so that the circulating-pumps can pump from the bilges as well as from the sea. This may be done by having pipes lead from the bilges to the main injection pipe. This bilge suction pipe is provided with a non-return valve, called the bilge injection valve, so that in case of a leak water may be drawn from the bilges and discharged overboard. When pumping from the bilges the sea-valve is closed and the bilge injection valve opened. This valve is similar in construction to an adjustable lift feed valve. When pumping from the bilges, this valve will allow water to pass from the bilges to the pumps, but when the pumps are drawing from the sea, the sea water holds the valve down.

The end of the bilge pipe should always be provided with a strainer, so that waste, chips, etc. will not enter the pumps. Bilge piping is almost always of lead as it is durable and easily fitted. The bilge water corrodes iron quickly unless it is well protected. Lead bilge piping should be inspected frequently because being easily flattened and dented it may be damaged so as to prevent or greatly reduce the flow of water.

DIRECTING-BOX.

To simplify the bilge piping and to allow the various pumps to draw water without complex piping, all the bilge suctions are usually led to a rectangular box or chest called the **directing-box, mud-box** or **communication-box.** This is a rectangular, closed cast-iron chest, situated in the engine-room near the pumps. It is divided into two compartments by a strainer. All the suction pipes of the various pumps are connected to one end of this box by valves. The bilge pipes are connected to the other end by valves or stop-cocks. Thus any pump may draw from any bilge through the same pipe if the valves are properly arranged. As this box has considerable capacity the velocity of the water will be slight, and consequently the sediment will either be deposited or caught by the strainer. The cover should be easily removed, so that the interior may be examined and the strainer cleaned.

DELIVERY VALVES.

Delivery or discharge valves should be fitted to each outboard delivery pipe at the outlet. This valve is simply a check-valve or non-return valve having a spindle passing through the covers, so that they may be lifted or pressed down on the seats. It is arranged so that water may be discharged from the ship but no sea-water can flow back. If the valves have no external spindles, no one knows whether or not they are shut.

WATER SERVICE.

In order to supply cold water to the thrust-block, crosshead slides, eccentrics, and the various bearings, a system of piping is installed. The pipes lead from the sea, condenser, or from a donkey pump to the points where the water is needed. Water for the bearings and the various parts of the engine is usually taken from the sea, while the water for the thrust-bearing is taken from the stern tube or from the sea. If the water is taken from the sea, the pressure is sufficient to cause the flow. In case of stoppage a pump is put in to clear the pipes.

In large ships a fire main runs around the ship; from this pipe branches lead to the various stations. The fire system carries a pressure of 25 to 40 pounds, and is useful for washing decks and flushing. The system is piped both from the sea and from the bilges.

MANAGEMENT OF ENGINES.

It is of great importance that the chief engineer and all of the assistants should be familiar with the machinery of the ship. The steam and exhaust pipes, both main and auxiliary, and the location of the valves should be traced; also the feed pipes to the boilers, and the piping to the condensers. It is necessary that each officer should know the function of every pump and the piping from the bilges. Unless the engineer on watch is well acquainted with all the machinery he cannot act promptly in case of emergency but will be compelled to send for the chief or find someone under him who can furnish detailed knowledge of the part in question. The promptness and confidence with which he can act at all times depend upon his knowledge of all the parts of the machinery.

Before Starting, Just what to do before starting depends largely upon the prevailing conditions and the arrangement of the machinery. In general the following should be observed:

All gear used in port or for repairs should be stowed away and all covers replaced. Such valves as the inlet and outlet valves of the circulating pump and all valves to bilge pipes should be tried and put in proper condition. The outboard delivery valves from all pumps should receive especial attention. The valves to jackets and the bulkhead and regulating valves should be opened and inspected. The valves in the main steam pipe should not be closed tightly or they will be set fast when steam enters.

The oil-cups and lubricators should be examined and put in good working order and the necessary worsteds adjusted.

The various joints should be inspected and the glands packed.

Pressure and vacuum gages should be connected and the shut-off cocks tried.

The bright parts of the machinery that are likely to become splashed with water should be oiled.

Auxiliary engines should be tried by steam if possible; if not, by hand. Such auxiliaries as the steering engine, circulating engines and the electric-lighting engines should receive careful attention. In all cases, the reversing engine should be tried before using the main engines and before entering port it should again be tried to make sure that it works properly.

The main engine should be oiled at all the rubbing and rotating parts.

An important item is the examination of the crank-pits and all the working parts. If these parts are not examined, some obstruction may prevent the engine from starting. The main engines should be turned through at least one revolution, both ahead and astern, by hand.

In case forced draft is used with closed stokeholds, the draft gages should be cleaned and filled with water and the air-tight doors should be examined and rigged. The fans should be carefully oiled and adjusted.

To Start the Engine. In starting an engine the engineer in charge must use the knowledge gained from experience as no set rules will apply to all engines. For instance, a small single cylinder engine is not started in the same manner as a large triple expansion engine. In the following we will consider the types of machinery most used — the triple expansion engine and surface condenser.

In general, to start an engine it is first necessary to warm the cylinders and form a vacuum in the condenser; the engine can then be started by admitting steam to the cylinders.

To form the vacuum. It is usual to fit an independent circulating-pump so the Kingston or sea-valve should be opened and the discharge valve tested to see if it lifts readily. The circulating-pump is then started so that the condenser will not become heated by the drains and exhaust steam. The auxiliary air-pumps should then be started to keep the main and auxiliary condensers free from water and to form a partial vacuum. If the air-pump for the main condenser is independent, it may be started so as to form a vacuum.

To warm the engines, all cylinder, receiver and steam chest drains are put in communication with the condenser. In order to ascertain whether or not the drains are working properly a by-pass arrangement is often fitted. This arrangement connects the drains to the bilges. The jackets are usually trapped to the hot well or feed tanks but can be drained directly to the bilges. If all the drains are in order, open slightly the throttle valve and all valves in the main steam pipe. This will admit a little steam to the high pressure steam chest. Steam is also admitted to the jackets to assist in warming the cylinders.

Now open the by-pass valves a little to admit steam to the receivers. The steam in the receivers finds its way into the cylinders and helps in the warming up. To warm both ends of the cylinders move the valve gear back and forth slowly from full gear ahead to full gear astern. This is done by moving the weight shaft by means of the worm and wheel. The throttle may now be opened a little wider, enough to set the engine in motion. By means of the reversing gear the cranks can be made to move back and forth without making a complete revolution.

We will assume that the engine is thoroughly warm and (as the drains are open) free from water. Steam is in the jackets, and the starting-engine and starting-valves ready. The centrifugal pump is at work circulating water through the condenser and either the auxiliary air-pump or an independent air-pump is at work.

To start the engines run the links into full gear ahead or astern and open the throttle valve. In case the engines do not start, use the by-pass or auxiliary starting valves. The engines should be started slowly and the speed gradually increased by admitting more steam. After the engines have made about 200 revolutions the drain cocks may be closed.

Marine engines may fail to start from many causes, but if proper precautions are observed before trying to start there should be no difficulty.

Among the causes which are not apparent from the exterior are:

The throttle valve spindle may be broken.

The high pressure valve (if a slide valve) may be off its seat and admit steam to both ends.

The engine may be gagged; that is, the throttle will supply steam to one side of the high pressure cylinder and the by-pass valves admit steam to the opposite side of the intermediate or low. In this case the engine will not move, as the pressures are equal.

ized. In using the by-pass valves, the valve or valves should be used which will produce a turning moment on the shaft. Let us suppose that both the high and low pressure valves cover the ports, and the intermediate slide valve is in such a position that steam can enter that cylinder. If now the throttle is opened, the engine will not start because both ports are closed. If the by-pass valves to both receivers are opened, steam will be admitted to the proper side of the intermediate piston. Also the steam in the low pressure receiver will find its way through the exhaust cavity of the low pressure slide valve to the other side of the intermediate cylinder. The result will be that the engine will not start because the high and low are not available for starting and the pressures on the intermediate piston will balance. In this case steam should be admitted to the intermediate receiver only. If steam is admitted to the low pressure receiver only, it tends to force the intermediate valve off its seat.

The opening of the wrong starting valves will frequently produce a similar situation.

If the engine has become gagged, it should be freed from steam. This may be done by closing the throttle and moving the link to the opposite extreme position. The engine can then be started in this direction and then be quickly reversed; or it may be started in the proper direction if the mistake is not repeated.

The valve stem may have become broken inside the chest or the valve may have become loose on the stem.

One of the eccentrics may be broken or slipped on the shaft.

Bearings set up too tightly or too much compression on the packing in stuffing boxes often prevent starting.

The propeller may be fouled by a rope or other obstruction.

The turning gear may not be disconnected; that is, the worm may still be in gear with the worm wheel.

After the engine has been running for a short time, the following **adjustments** should be made:

The speed of the feed pumps to maintain the proper water level in the boilers.

The supply of circulating water to the main condenser. The amount of circulating water should be such that the temperature of the feed will be from 90° to 125°, averaging about 110°.

The amount of circulating water around the main bearings should be reduced as low as possible to relieve the work of the bilge pumps.

The pressures in the steam jackets and the valves in the drains should be regulated.

Lubrication of Bearings. The oil cups on bearings require special attention. The caps of lubricators should be kept in place on the oil cups to prevent dirt and water from entering. The lubricators should be examined frequently because the pipes and passages are likely to become clogged with dirt or the worsteds may work downward and fill up the oilways.

Crank-pin bearings are lubricated by a wiper on the crank-pin box with the oil cup over it. Both crank-pins and eccentrics are frequently oiled by a centrifugal lubricator already described.

Internal Lubrication. In most engines the steam is sufficiently wet to insure internal lubrication. For this reason, very little oil is supplied to the cylinders. In many modern engines no lubricators are fitted. In case they are fitted, they should be of the sight-feed type as explained in discussing the Steam Engine. It is advantageous not to use oil in the cylinders as it is then much less trouble to keep the boilers free from grease.

Hot Bearings. There are many causes for hot bearings. The most common cause is dirt. To prevent the accumulation of dirt in the bearings the engine room should be kept clean and the oil cups and pipes kept clean. The bearings should be opened and cleaned whenever convenient.

Insufficient and improper lubrication will almost always cause heating. If the oil enters at the top where the pressure is greatest, suitable oil ways should be cut to allow the entrance of the oil. Another method is to lead the oil to a point of low pressure.

Other causes are improper adjustment or alignment and deficient surface. These defects lead to excessive pressure in some parts which causes heating.

In many large, modern engines, the main bearings have the castings cored out so that water circulates through the bearing continuously but does not come in contact with the rubbing surfaces. In the caps there are holes to allow the hand to feel of the bearings and to allow air to circulate. The temperature of the circulating water and the hand test indicate the condition of the bearing.

In case a bearing tends to become too warm the amount of circulating water is increased. In extreme cases of heating, the bearing may be flooded with water, thus washing out all of the dirt and reducing the temperature. If this water douche is used, plenty of oil should be supplied and the bearing given careful attention.

It may be necessary to slack back the nuts on the caps for a short time, but they should be slacked but little or there will be pounding. Sometimes the power distribution may be temporarily altered, that is, the power given out by any one cylinder may be decreased, and the power given out by the others increased by running the link in or out and adjusting the expansion gear. It may even be necessary to reduce the speed for a time, but this is not done unless necessary as it causes delay.

If the bearing is discovered to be *hot* the water service should not be applied as the sudden cooling may cause fracture. In this case the engine should be slowed down or stopped and the bearing cooled with oil, sulphur, or a mixture of soft soap, water and oil.

Bearings that are lined with white metal should receive special attention as the white metal soon becomes plastic and melts at about 400°F.

The water douche should be used only in extreme cases and with caution because it may cause fracture and is likely to corrode and destroy the bearings. If water must be used, the parts should be cleaned and oiled as soon as the engines stop.

Hot Rods. Piston-rods and valve-rods are often kept lubricated by means of a large brush called a swab. Frequently in starting, a man with a swab is stationed to keep the rods cool. If these rods become warm because of tight glands, they may be cooled by slacking back the gland and applying water and oil by means of a swab or syringe. If the rod is hot and water applied, one side may be cooled and shortened ; the result will be a bent rod. Instead of water, the engines should be eased If the rod cannot be felt, a few drops of oil or water syringed on the rod will show whether or not it is hot. If hot, the water will hiss or the oil will burn and cause smoke.

As with bearings, piston-rods that are packed with metal packing should receive careful attention, as the packing may run and cut the rods. The principal causes for hot rods are glands too tight or not properly packed, piston-rod not in line and insufficient lubrication.

Knocks. Bearings should be adjusted while the engines are running. If a bearing is loose it will knock at both ends of the stroke. Usually knocks can be located by the sound or by the feeling. Knocking in the cylinder may be due to a loose or broken piston ring, piston loose on the rod or a nut or bolt loose. If knocking occurs, open the cylinder and jacket drains, to be sure it is not due to an accumulation of water. If the noise continues at various speeds it is probably due to looseness of the piston rings. If this is the case the ring must be rescraped and fitted.

Jackets. The pressures in the jackets should be maintained at the desired amount. The jacket drains are led either to the condenser or to the feed tank. If led to the feed tank the temperature of the feed water is then raised. The jackets should be well drained, as water causes a crackling noise at each stroke. The remedy is to open the drains wide, and when clear of water, regulate the drain valves by increasing the opening.

Bilges. The bilge pumps should be at work constantly while the vessel is steaming, so that water will not accumulate in the bilges or crank pits. The crank pits should not be in communication with the bilges, or the oil from the crank pits will be spread over the bilges. If the stokehold bilges empty into the engine room bilges the bilge water should be strained, on account of the fine coal in the stokeholds. Strainers should be carefully attended to, as fine coal, waste and articles carelessly left in the bilges are likely to choke them. It is considered good practice to pump from wells about 8 inches deep, formed in the bilges and covered with strainers.

Linking Up. When starting, the links are placed in full gear. When running at the required speed the engine is linked up so that the expansive working of the steam may be utilized. The best position of the links for a given speed is determined by experience. Trial will show at what position the engine will run smoothly, economically and without too much noise. The throttle valve should be wide open so that steam will enter the high pressure chest at nearly boiler pressure. If the engine is running at reduced speed it is a good plan to link up the high pressure engine by the use of the block in the slot of the arm on the weigh shaft. This will increase the total ratio of expansion but will not reduce the port opening of the intermediate and low pressure cylinders. If there is any probability of a change in speed, the engineer in charge should see that the starting engine is warmed and drained from time to time and be sure that it is ready for use. Grunting of the slide valves is sometimes stopped by running the links into full gear for a short time then adjusting them in a slightly different position.

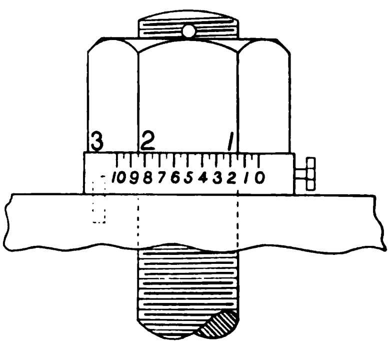


Fig. 46.

Marking off Nuts. In order to have a record of adjustments and to aid in adjusting bearings the following marks are made. At each corner of the hexagonal nut near the face that bears on the washer, a number is stamped as shown in Fig. 46. The washer is prevented from moving by some device. A part of the circumference of the washer is marked off in say 10 divisions about one-half inch apart These divisions are then sub-divided and numbered. It is then easy to record the position of the nut by noting what number on the washer coincides with the corner of the nut. Thus, 1 on $1\frac{1}{2}$ or 2 on $8\frac{1}{2}$.

Refitting Bearings. To find out whether or not a bearing needs refitting and to ascertain the amount of play, a lead is taken. The cap is first removed and a piece of lead wire is laid along the journal parallel to the axis. Some engineers place two pieces around the journals near the ends and others place them diagonally. The cap is then replaced and screwed down hard on the liners. The cap is again removed and the leads taken out and examined. They should be flattened uniformly. The thickness shows the clearance. If the marks on the nuts at which the leads were taken are noted they may be compared with the marks and leads taken sometime afterward and the location and extent of wear known.

If the leads show that the bearing needs refitting, the caps are first removed and the journal, caps and oilways cleaned. The journal is then carefully calipered and if found oval, cut or rough, should be filed all over until smooth and true. This process requires considerable care and skill for the new surface must be concentric with the axis. The filed surfaces are smoothed by an oil stone or emery. If emery is used, care must be taken to clean all surfaces.

After the journals are in proper condition the brasses, if used, are fitted by filing and scraping. A little red lead smeared on the journal will assist in the fitting. The brasses should be eased away at the sides as the metal at those points is of no assistance but increases the friction.

If the bearings are lined with white metal they must be relined when the white metal is worn through. To do this a mandrel of the same size as the journal is placed in position in the bearing and the molten metal poured in or the strips of white metal are hammered into the recesses. The metal stands clear of the brass about $\frac{1}{4}$ inch when finished.

STOPPING.

When near port the fires should be burned light so that there will be no difficulty in keeping the steam pressure down. If the pressure rises when the engines are slowed down there may be an unnecessary waste of fresh water on account of the blowing of the safety valve; the loss of fuel will also be considerable.

Before entering port have all ashes dumped overboard and pump out all the water possible from the bilges. The reversing and capstan engines should be warmed ready for use. When the engines are slowed down, the water service should be shut off and the oil supply increased to prevent rusting of the bearings while in port. The pressures in the receivers and jackets should be watched as they have a tendency to rise when the engines slow down.

When the engines are done with, the valves in the main steam pipe and the jacket valves should be closed but not too suddenly; the steam should then be allowed to escape from the pipe or used up by the reversing or other auxiliary engine. All drains and receiver relief valves should then be opened and steam shut off from the steering and reversing engines.

The hand turning gear may be put in gear as soon as there is no steam left in the engine room main steam pipe. The engines should now be cleaned while warm by wiping down the rods and shafting with cotton waste and oiling the bright parts to prevent rusting.

In case the engines are stopped suddenly, notice should be immediately given in the fire room so that the draft may be checked and the evaporation reduced. If the water level is low, water should be pumped into the boilers. Every precaution should be taken to prevent an over-supply of steam but if it is impossible to prevent the rise of pressure the excess of steam may be used in the evaporators, distillers, etc., and in pumping out bilges and crank pits. The engines should be kept warm and well drained so as not to cause delay in starting. If the air-pump is worked by an independent engine, it should be kept working for a time so that the condenser will not be flooded with water and injure the air-pump. If the air-pump is worked from the main engine, it will of course stop as soon as the engines stop; in this case put on a feed-pump to keep the condenser free from water. The circulating engines may be stopped soon after the engines stop.

As in the case of entering harbor, watch receiver and jacket pressures and stop the supply of water to bearings, etc. If there is any chance of starting again soon, keep the reversing engine warm and well drained.

If the stay in port is to be long, the main condensers and air-pumps should be well drained and several of the boilers may be cleaned and repaired if necessary. The fires should be allowed to burn themselves out gradually. If the stop is for a short time, the fires should be banked.

EMERGENCIES.

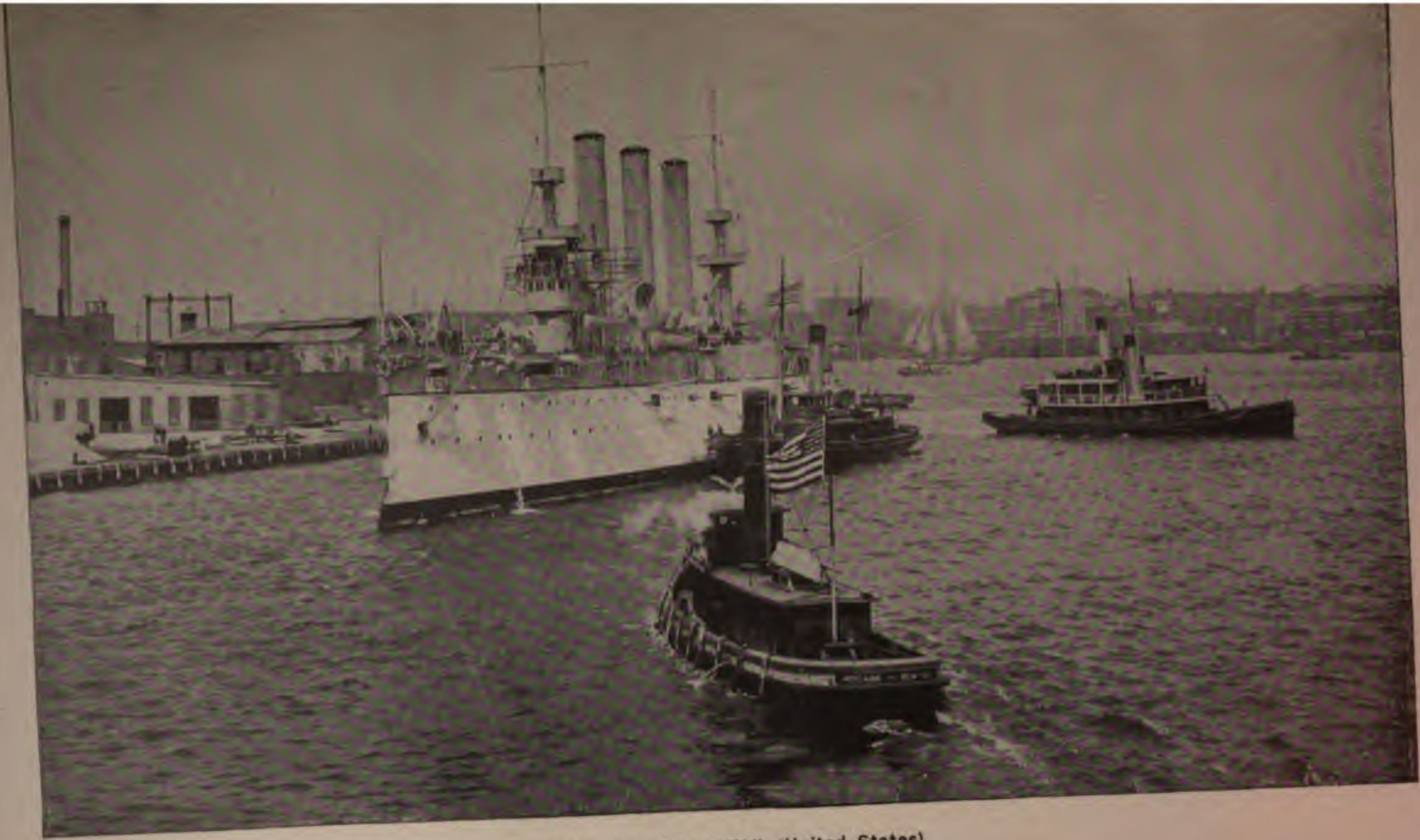
What to do in emergencies depends upon the arrangement of the machinery. The kind of engine, number of engines and arrangement and capacities of the condensers and auxiliary machinery often determine what course to pursue in case any part breaks or gets out of position.

Cylinder Head Broken. If a cylinder head breaks it should be repaired if proper means are at hand. If it cannot be repaired, the steam port which admits steam to that end may be blocked up by driving in plugs of soft pine and the engine run single acting. This is comparatively simple if the valve is a plain slide but with a piston valve the many ports make it more difficult. If a cylinder head of a triple expansion engine breaks, and one engine must run single acting, the expansion gear should be arranged so that the work will be properly divided.

Fracture in the Crank Shaft. What to do in this case depends upon many conditions. If the engine is of the multi-cylinder type, and the crank shaft is made in interchangeable lengths, fit the spare length in place of the disabled one. In case no spare length is carried and the crank shaft of the low pressure engine is damaged slightly, change the low pressure length to the high pressure engine and place the high pressure length in place of the low. The low pressure length transmits the most power. If the damage is considerable, such as the breaking of the crank-pin, the length cannot be used and the high pressure engine must be disconnected. If the pumps are worked from the high pressure crosshead, repair the broken shaft, place it in the high pressure engine and block up the steam ports to the high pressure cylinder. The power is then developed in the intermediate and low pressure cylinders; the amount of power transmitted to the high pressure crank shaft being just sufficient to work the pumps. Probably it will be necessary to run the engines slowly because of the weak shaft.

Piston Broken. If the piston, piston-rod or valve stem becomes broken and cannot be repaired, the damaged engine must be disconnected and the power furnished by the others.

Air-Pump Broken. In case the air-pump breaks and cannot be repaired the exhaust may be carried to the deck and the engines run non-condensing. This is a great disadvantage if the amount of fresh water carried is slight and the ship is far from



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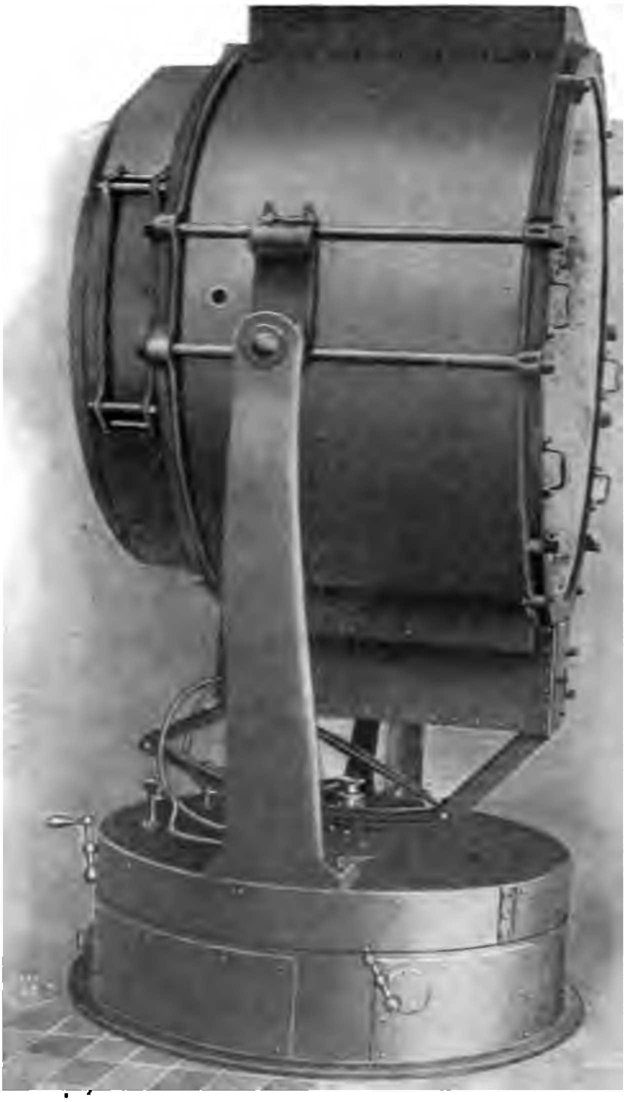
port. In case no separate exhaust is possible, the auxiliary air-pumps may be connected and the ship proceed. In most cases, however, the auxiliary air-pumps are not of sufficient capacity to remove all of the condensed exhaust steam and the air; therefore no vacuum will be carried but the condensation may be returned to the boilers.

Bent Piston-Rod. In the case of a small rod and a long slight bend, the rod may be straightened by placing it in a lathe and applying a powerful lever. A large rod or one with a quick bend, should be heated to a dull red in a wood fire. The rod is then placed in a large lathe and straightened by a hydraulic jack. In doing this work care must be taken that the rod is not heated too hot, does not scale and the points of contact are protected by copper plates.

Eccentric Broken. If the go-ahead eccentric or eccentric rod breaks and cannot be repaired, the go-astern eccentric can be shifted in its place. The engine will now run ahead but cannot be reversed. The go-astern end of the links must be kept from dropping by some flexible support such as a rope or chain.

Another method is to disconnect the connecting-rod from the crank-pin and crosshead of the disabled engine, and block up the steam ports so that the steam will flow to the other cylinders by the shortest passage. The piston should be secured on the bottom of the cylinder. The valve should be removed. After removing the broken valve gear the engine is ready to start. This method may be used if the pumps are worked from the low pressure crosshead and the low pressure engine is intact. If, however, the high pressure eccentric is broken and the pumps are worked from that crosshead the same method may be pursued as described for a fractured crank shaft. That is, the valve gear should be removed, the ports blocked and the piston, the piston-rod, crosshead and connecting-rod left in place. The moving parts of the high pressure engine will then work the pumps by means of the power transmitted to the high pressure crank. The engine must be run slowly but can be reversed.



60-INCH ELECTRICALLY CONTROLLED SEARCHLIGHT PROJECTOR
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NAVIGATION.

Although elementary in character, this book is complete enough to enable the student to solve the ordinary problems of navigation. It is, therefore, essential that the student, if he wishes a mate's or a master's paper, thoroughly understand the contents. As the student has already studied arithmetic, geometry and trigonometry, these subjects will not be repeated except in a few cases. This is not a book on seamanship, but is intended for seamen who know little of the subject of navigation. Ignorance of navigation often blocks the way to a position of command.

As most navigators have at hand several reference books, such as "American Practical Navigator" by Bowditch and "Wrinkles in Practical Navigation" by Lecky, these books have been referred to for tables, etc.

DEFINITIONS.

A sphere is a solid body, every part of whose surface is equidistant from a fixed point within, called the center.

A diameter of a sphere is any straight line passing through the center and extending in both directions to the surface.

A great circle is any circle whose plane passes through the center of the sphere. The center of the sphere is the common center of all great circles.

The shortest distance between any two points on a sphere is the *arc* of a great circle passing through those points.

A *small circle* is any circle whose plane does not pass through the center of the sphere.

A spherical angle is the angle or inclination of two great circles of a sphere which meet one another.

A spherical triangle is the geometrical figure formed on the surface of a sphere by the intersections of arcs of three great circles.

The earth, generally speaking, is a sphere, and revolves about one of its diameters, called the axis, once in every twenty-four hours. The extremities of this axis are called poles, one the north and the other the south pole; in Fig. 1 N S is the earth's axis, N being the north and S the south pole.

Equator. This is an imaginary great circle dividing the surface of the earth into two parts, called hemispheres, the north and south. The equator, which is also commonly called the "Line," is represented in Fig. 1 by Q T.

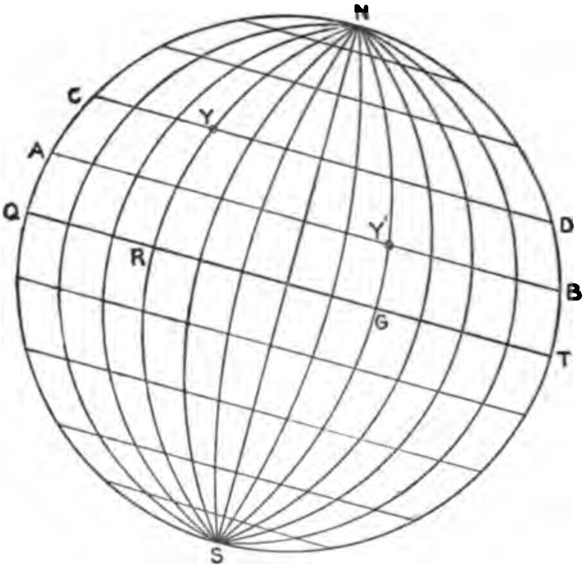


Fig. 1.

Meridians. These are great circles on the earth's surface drawn through both poles and at right angles to the equator. They are called meridians because they mark the places which have noon at the same time. For instance, N Q S of Fig. 1 is a meridian, also N R S, and the other curves drawn through N and S. All places on N R S have noon at the same time. Any two places which lie exactly north or south of each other are said to be on the same meridian. One particular meridian, the one passing through the observatory at Greenwich, England, is taken by the English and American nations to be the first, or prime, ridian.

Longitude. The longitude of a place is the distance of its meridian, or the meridian passing through it from the prime meridian; this distance is measured on the equator in degrees, minutes and seconds. Another definition is: longitude is the angle at the pole between the two aforesaid meridians. In Fig. 1 let Y be a place on the meridian N R S, and let N G S be the prime, or Greenwich, meridian; then G R is the longitude of Y and is west of the prime meridian. All places lying between the prime meridian and the 180° meridian in a westerly direction from the prime meridian are in west longitude, and in east longitude when lying between the same meridians in an easterly direction from Greenwich. The 180° meridian is just halfway around the world from the Greenwich meridian.

Parallels. Parallels of latitude are small circles parallel to the equator, as A B, C D, etc. (Fig. 1). All places on parallel A B, for instance, are exactly true east and west of each other.

Latitude. This is the name given to the distance of a place north or south of the equator, expressed in degrees, minutes and seconds measured on a meridian. In Fig. 1, Y is on the parallel C D, and its latitude, expressed in degrees, minutes and seconds, is the arc R Y of the meridian N R S. We can now see how latitude and longitude determine the position of any ship or other object on the surface of the earth, for longitude fixes its distance east or west of Greenwich and latitude its distance north or south of the equator. The equator, meridians and parallels of latitude are of course purely imaginary lines and are used simply as a means of locating position.

The Difference of Longitude between two positions is the distance measured on the equator between their meridians.

The Difference of Latitude is the distance between the two parallels of latitude on which the two positions are situated measured on a meridian. The difference of longitude between Y′ and Y (Fig. 1) is G R, the difference of latitude is B D, A C, or the distance between the parallels A B and C D measured on any meridian.

Departure is the distance in nautical miles made by a ship due east or west, according as it is sailing toward the east or the west, and is commonly called "easting" or "westing." Easting or westing is expressed in ***nautical miles***, and is unlike longitude in this respect. It might seem at first sight that departure and longitude were one and the same thing, but as already stated, longitude is expressed in degrees, etc., while departure is expressed in nautical miles. The difference is this: the distance of length of a degree of longitude grows less as we go north or south from the equator, while the distance of a nautical mile is the same everywhere. The distance of one nautical mile on the equator is equal to one minute of longitude; north or south of the equator the distance of one mile is greater than one minute of longitude. It will therefore be plain theoretically it is better to make easting or westing in as high latitudes as possible, for the higher the latitude the shorter the distance necessary to sail in order to change the same distance of longitude.

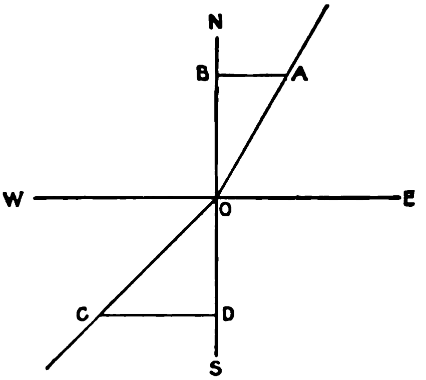


Fig. 2.

The course steered is the angle between the meridian and the ship's head. The course made good is the angle between the meridian and the real track of the ship.

In Fig. 2 let N S be a true north and south line, or meridian, and W E an east and west line, or parallel. Now let O A be the direction along which the ship sails in going from O to A; then O A is the distance sailed, O B the difference of latitude, B A the departure, and the angle B O A the course; similarly, O C is the distance sailed, D O the difference of latitude, C D departure, and D O C the course.

Nautical Miles, or Knots. A great circle of the earth is divided into 360 degrees, each degree into 60 minutes, and each minute into 60 seconds. Each minute is 6,080 feet (nearly) in length, or one nautical mile, the statute mile being only 5,280 feet.

Rhumb Line. This is the line on which the ship sails as long as her course is not altered; it forms a curve upon the earth's surface which meets every meridian at the same angle. It coincides with a meridian when sailing true north or south, and with a parallel when sailing true east or west. The angle between the rhumb line and the meridian is the course.

THE COMPASS.

Before taking up the actual problem of navigating the ship we must consider the compass and its behavior, together with its corrections. A short description of this most important navigating instrument will be sufficient; its action and errors, however, will be explained at greater length. The mariner's compass consists of a circular brass card C (Fig. 3), covered with white enamel, on which are marked the points and degrees as shown. The figure shows marks at 10 degrees, but a regular compass has the one degree marks as well. The smaller compasses often do not have degree marks, but simply the points. B represents the edge of the compass bowl, which swings in gimbals and is carried in a binnacle. A is a spheroidal air vessel, N are the bundles of magnetic

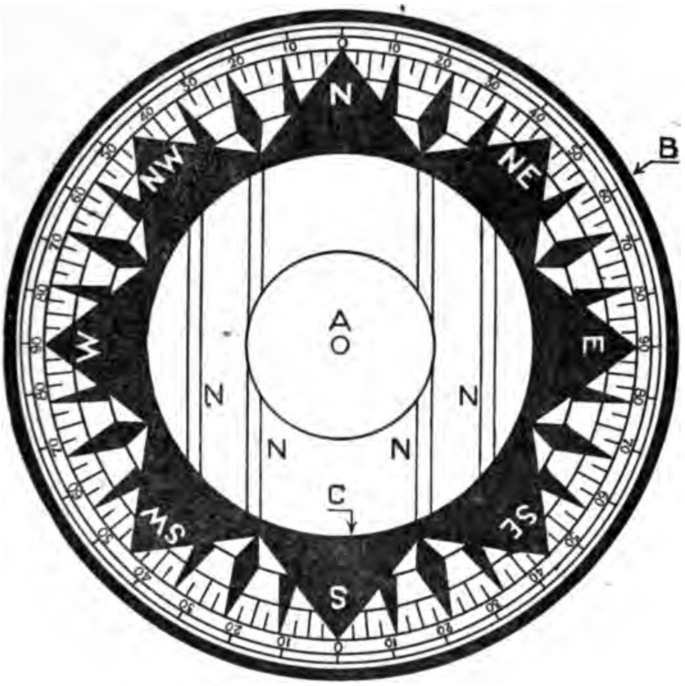


Fig. 3.

needles. The card, needles and air vessel are fastened rigidly together and rest on a pivot at the center of A, the bowl being filled with alcohol and covered by glass.

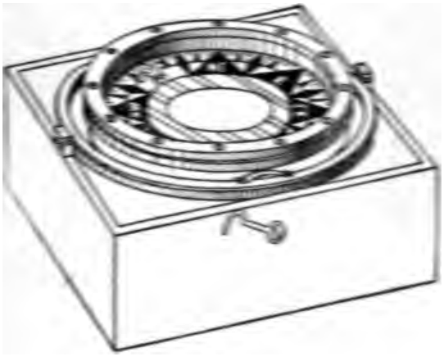
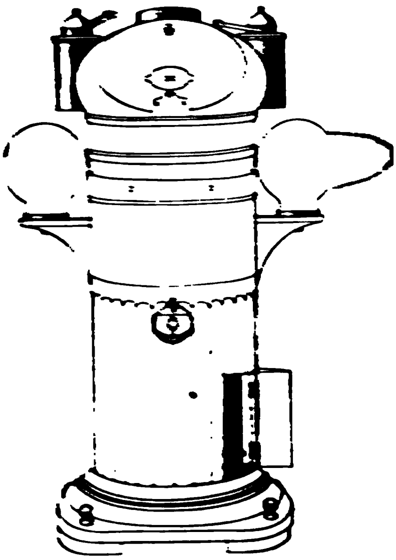


Fig. 4.



BINNACLE.

Fig. 4 shows a compass in a box, and Fig. 5 an improved form of compass card.

The circular card is divided into degrees and points to represent every different point of the horizon. Every circle being divided into 360 degrees, and there being 32 points to the compass card, the angle between the single points will be $\frac{1}{32}$ of 360°, or 11° 15′. The points of the compass are as follows, commencing at the north point and going around right handed:

N, N by E, NNE, NE by N, NE, NE by E, ENE, E by N,
E, E by S, ESE, SE by E, SE, SE by S, SSE, S by E,
S, S by W, SSW, SW by S, SW, SW by W, WSW, W by S,
W, W by N, WNW, NW by W, NW, NW by N, NNW, N by W.

Each point is further divided into quarter points: for instance, ½ a point E of N is called N ½ E, a quarterway between SW and SW by S is SW ¼ S, and so on. These points, or "boxing the compass," as it is called, should be well learned.

A course is spoken of commonly as a 1, 2, 3, or 4 point course, as the case may be: for instance, N by W is a 1 point course, NNE, SSE, SSW, NNW are 2 point courses, NE, SE, SW and

NW are 4 point courses. It will be seen at a glance that the notation is not difficult.

Naming the Course. As already stated, the course is the angle reckoned from the N or S towards E or W; for instance, if a ship is steering by compass N by E, the course is a one-point course, and is one-point to the right of N. E by S is not a nine-point course, but a seven-point course, seven points to the left of S.

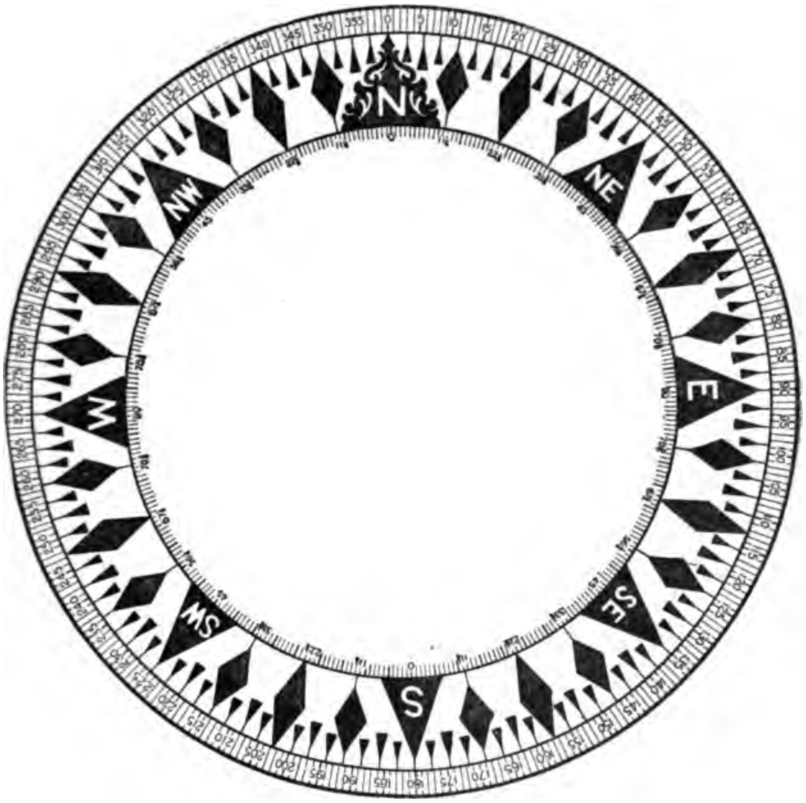


Fig. 5.

E and W are eight-point courses, in reality, although never spoken of as such.

On the inside of the compass bowl is a vertical black line in the direction of the ship's bow; this line, called the lubber line, shows the helmsman the direction of the ship's head. If, for example, he is told to steer SSE, he puts the helm over so as to bring the lubber line opposite SSE on the compass card.

Magnetism. [illegible] is not known, but through careful study [illegible] formulated which govern all magnets. There [illegible] kinds of magnets, natural and artificial. The earth is [illegible] compass needle an artificial. The ends of [illegible] the magnetism at one pole [illegible] inasmuch as its properties are different. [illegible] pole north and the other south. [illegible] brought up to the north pole of [illegible] if placed near the south pole it will attract; [illegible] repel and unlike poles attract. This law [illegible] compass needle; as the earth is a magnet, [illegible] will attract the pole of another magnet. The magnetic pole of the earth in the northern hemisphere is called the north magnetic pole, and while the north point of the compass [illegible] attracted toward the north magnetic pole, [illegible] opposite. If we consider the north magnetic [illegible] north magnetism, then the north point of the compass needle is, according to the law stated, [illegible] confusing, but if we call the magnetism [illegible] which is attracted by the earth's north [illegible] magnetism, and that of the opposite [illegible] confusion may be overcome. [illegible] that the north point of the compass [illegible] the south point south-seeking [illegible] end of a magnet is often [illegible].

The north magnetic pole of the earth is not situated at the real [illegible] approximately 70° 5' North Latitude, 96° 46' West Longitude.

Dip of Needle. A magnetic needle balanced on its center of gravity, [illegible] does not remain horizontal, but its north [illegible] hemisphere points downward, or dips. At the magnetic poles the needle would be vertical, while [illegible] would be horizontal.

[illegible] very seldom points true north [illegible]. The angle between the needle and the true [illegible] meridian, when free from any local attraction, is [illegible] place. The variation is always marked on charts, because the variation is different for different places, being E at some and W at others. By westerly variation we mean that the north point of the needle is pulled to the left of the true north, and easterly when pulled to the right. Suppose we are at a place where the variation is 22° 30′ W and that the ship's head is pointing true north, the north point of the compass will be drawn, owing to the variation 22° 30′, or 2 points, to the left of the true north, and would thus indicate that the ship was headed NNE. We know, however, that she is headed true north, hence to correct for variation we have the following rule: *When the variation is westerly the true course is equal to as many points to the left of the compass course as the variation, and when easterly the correction is applied to the right; looking in each case from the center of the card toward the point to be corrected.*

The following examples should be carefully studied, as this is a matter of importance:

Ex. 1. Compass course S $\frac{3}{4}$ W, variation $2\frac{1}{4}$ points E. True course $2\frac{1}{4}$ points to the right of S $\frac{3}{4}$ W or SW by S.

Ex. 2. Course by compass N by E, variation 2 points W. True course is 2 points to the left of N by E or N by W.

Ex. 3. Course or bearing N 84° E, variation 19° W. True bearing N 65° E.

Now if we have the true course and wish to find the compass course we apply the variation in the opposite way. Suppose we wish to steer a ship so as to reach a certain place which lies SW true from our starting-point, the variation being 2 points E, therefore we cannot steer by compass SW, but must steer by compass SSW, which is in this case the compass course. Practice in correcting courses is essential, and the student should keep at it until he thoroughly understands the process.

Deviation. The iron in the hull of a ship, the cargo in the hold, tanks, etc., and the subpermanent magnetism received while the vessel is being built, affect the compass. These elements cause an error called deviation. Whatever error arises from objects within a ship is called deviation; whatever by objects outside the ship is called local attraction. Closely connected with local attraction and deviation, we have what is known as permanent and subpermanent magnetism. All magnets have the power of imparting magnetism to certain other substances, when brought within their influence. Soft iron in any form is most susceptible to this power; and the earth being a great magnet induces, as it is called, magnetism in any iron body lying in the direction of its line of magnetic force or the magnetic meridian. If the iron body be kept for a long time in one position, and especially if it be subjected to hammering, the magnetism it is receiving from the earth becomes of a lasting character, and remains, to a certain extent, after the body is removed; as the poles of magnets induce magnetism of an opposite name in soft iron bodies under its influence, the part of the iron body which is pointed toward the north magnetic pole of the earth will receive red magnetism and the opposite part blue magnetism. It will now be understood why the direction of a ship's head during building, and the hammering to which she is subjected, cause a ship to acquire a large amount of induced magnetism, and this once hammered in, though it will be diminished by change of position, knocking about by waves, etc., will never, while the iron remains in the form of the ship, be entirely eradicated. This is subpermanent magnetism, so called. Therefore we see that another disturbing element is at work to change the direction of the compass needle or to produce error; this element being, as stated, iron used in the ship's construction, her equipment, or carried as cargo. These disturbing forces, permanent and subpermanent magnetism, have been named (according to the effects they produce on the compass needle) *semicircular* and *quadrantal deviation.*

Semicircular deviation is caused by subpermanent magnetism and induced magnetism in vertical iron, such as masts, funnels, etc. Its greatest effects are produced when the ship's head is on the cardinal points; it is called semicircular because it produces easterly deviation in one semicircle and westerly in the other.

Quadrantal deviation is caused by the induced magnetism in horizontal iron; it produces easterly deviation in one quadrant, westerly in the next, and so on. To sum up, vertical iron is semicircular in action, horizontal iron is quadrantal in its action.

The *heeling* of the ship alters the deviation by changing vertical and horizontal iron to inclined. It might seem that this was of little consequence; but such is not the case, and an intelligent navigator should understand this heeling error clearly, and allow for it. The effect of heeling error increases as the distance from the magnetic equator increases, at which place it is nothing. The following should be taken account of: In the northern latitudes on northerly courses heeling error may be expected to place the ship to windward and on southerly courses to leeward of her supposed position.

Leeway. The action of the wind, the trend of the sea, etc., tend to drive a ship to leeward, so that she does not move exactly in the direction toward which she is heading, but is driven out of her course somewhat. This amount is called leeway, and may be defined as the angle between the course which she is actually going and that which she is trying to go. The estimation of the amount of leeway is one of the tricks of the mariner's trade, so to speak; it may be judged by looking at the wake.

Referring to Fig. 6, let a ship be headed or steering as indicated by dotted line A B, but owing to the wind the ship actually goes in the direction A C; the angle C A B being the leeway.

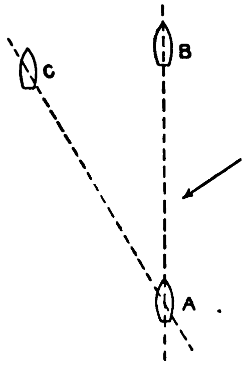


Fig. 6.

In correcting for *leeway* when on the *starboard tack* it must be allowed to the left, the same as westerly variation, etc.; on the *port tack* it must be reckoned to the right, the same as easterly variation.

CORRECTION OF COURSES.

From the foregoing discussion we know that the compass does not show the direction in which the ship is truly headed. It is plain that the navigator, knowing what course he has been steering by compass, must, in order to locate the ship's position accurately, find out the course he has actually made. Conversely, knowing the true course he must take in order to reach a certain place, he must know what the compass course shall be in order to make the place in question. This will be illustrated by an example, after stating the rules for correcting courses. It is of such importance that the student should study it carefully so as to leave no doubt in his mind as to how to correct courses.

To find true course from compass course. Put down your compass course, calling it so many points or degrees, then allow easterly variation to the right and westerly to the left; allow for deviation in the same way; leeway on the starboard tack is the same as westerly variation, hence is allowed to the left or away from the wind, and on the port tack the same as easterly variation.

Every master should know how to find the deviations of his compass. Now for a practical example of the use of the above-stated rules for correcting courses: Obtain a facsimile of a regular U. S. chart of a portion of the Atlantic coast, which is adapted from Atlantic coast chart No. 1,000, from Cape Sable to Hatteras. Let A B C D E F, etc., be the track of a vessel bound into Boston; it will be assumed that from A to F the wind has held N, ½ E, about a six-knot breeze, and that about the time the ship reached position F it hauled to NNE ½ E ; this would give nearly a fair wind for running to Boston, and it is now necessary to find what course must be steered to make Boston Lightship. We find by use of the parallel rule (referring it to the true compass card in the lower right-hand corner of the chart), or by the horn protractor (for description see page 28), that the Lightship bears W by N ½ N, which is our true course or course to be made good. Let the leeway be estimated at 1 point. The ship is on the starboard tack; we will assume that there is no bad steerage. Let the deviation be 1 point E; the variation given on above-mentioned compass card is 13½° W, which for simplifying we will assume as being 1 point W, to find compass course or course to be steered. True course = W by N ½ N. The variation being equal and opposite the deviation, they counteract each other, leaving 1 point leeway to be corrected or allowed for, which to find the compass course is allowed to the right or toward the wind, which makes the compass course WNW ½ N.

Now take an exact case

True course W by N ½ N = 73° 7½′ W
Deviation 10° E
Variation 13½° W
Leeway 11¼ Starboard tack same as W variation.
14¾° W

This is now allowed to the right of the true course N 73° 7½' W, and gives N 58° 22½' W, or NW by W, which is given to the helmsman.

Now suppose we had been sailing by compass for a certain number of hours NW by W, and that the leeway, variation and deviation were the same as in the above case; then in order to find the true course made good by the ship, we reverse the preceding methods and get as the true course W by N ½ N, which is necessary if the ship's track is to be marked upon the chart.

CHARTS.

A chart is a representation on a flat surface, such as paper, of a portion of the surface of the earth. Charts are made by several different projections. Harbors and small sections are made on what is called the Polyconic projection, while for great circle sailing (to be explained later) the charts used are on the Gnmonic projection. For general navigation, charts constructed on Mercator's projection are used almost entirely. A short description of Mercator's chart will be given, and a description of the other projections may be found in most books on Navigation.

Mercator's Chart. On this chart all the meridians and parallels are straight lines; the degrees of longitude are all equidistant; the degrees of latitude are increased in length from the equator to the pole in the same proportion as the degrees of longitude actually decrease on the earth's surface.

Use of Chart. The chart is spread out on a chart table, with the south end nearest the navigator. General charts for ocean sailing, and covering considerable extent, such as a chart of the North Atlantic, have, in addition to the true meridians, the magnetic meridians or lines of equal variation, also small compass cards (see chart). Under the title of the chart sufficient explanation is given whereby the chart may be read.

Parallels and meridians are at right angles to each other.

Scale of Latitude and Distance. The two meridians which bound the chart, as 67° and 75°, are called graduated meridians, because they are marked to degrees and minutes. On these meridians *latitude* is measured from the equator toward the pole in degrees and minutes, according to the scale of the subdivisions. *The distance between two places is also measured on a graduated meridian ; a minute being equal to one mile.*

Scale of Longitude. The two parallels which bound the top and bottom of the chart are called graduated parallels, 44° and 40°; they are also marked to degrees (and minutes, if the scale is large enough). *Longitude* is measured on these parallels and nothing more; the *distance between two places cannot be measured on the parallels.* On Mercator's chart the track of the ship, or rhumb line, is straight.

To Find Latitude of a Place on the Chart. With the dividers (for description see page 28) take the distance of the place from the nearest parallel, and refer this distance to one of the graduated meridians, placing one point of the dividers on the same parallel, and the other upwards or downwards, as required; read off the latitude at the latter point. Or by parallel ruler (see page 28) lay the edge of the rule on the nearest parallel of latitude, and work it to the given place; note the degree and minute on the graduated meridian at the edge of the rule. For example: In chart point C is found to be in the latitude 41° 29′ N. The student should find the latitude of all the points A, B, C, etc.

To Find the Longitude of a Place on the Chart. With the dividers take the distance of the place from the nearest meridian, and refer this distance to one of the graduated parallels, placing one point of the dividers on the same meridian, the other point to the right or left, as required; read off the longitude at the position of the latter point. It may also be done with a parallel ruler in the same manner as the latitude was found. For example: Point C, chart, has longitude 69° 26′ W (repeat for other points).

To Mark a Ship's Position on a Chart. We will assume that we know the latitude and longitude to be lat. 41° 29′ N, long. 69° 26′ W; with the dividers, take from the graduated meridian the latitude 41° 29′, and mark this up on the meridian nearest to the given longitude (in this case [chart] the 69° meridian); lay the edge of the parallel ruler on the nearest parallel, and work it to the exact latitude you have marked on the 69° meridian; then with the dividers pick off the given longitude (in this case 69° 26′ W), and lay this distance along the edge of the

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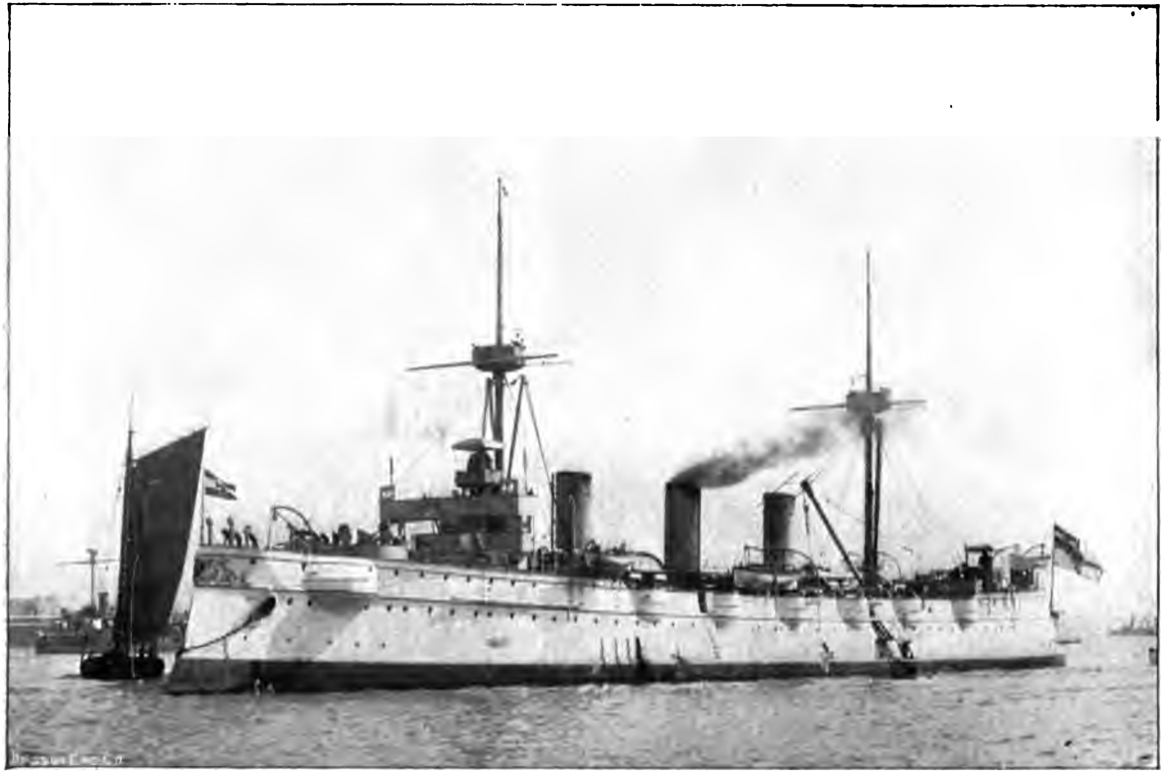


GERMAN CRUISER "KAISERIN AUGUSTA"

parallel ruler which already marks the latitude, and you have the ship's position. In this way a ship's track is usually pricked off at sea, her latitude and longitude being laid down every day at noon, or at any other required time, and the points thus obtained are connected by pencil line, which shows the track of the vessel.

To find the distance between any two places on the chart: Find the latitude midway between the two places on one of the graduated meridians, and mark the point: then with the dividers pick off half the distance between the two places on the chart; now place one point of the dividers on the midlatitude point mentioned, and mark with the other point above and below the midlatitude point, the distance between the upper and lower points being the distance wanted. Now let it be understood that the distance found on the graduated meridian is in degrees and minutes, which may be changed to nautical miles by bearing in mind that one degree of arc equals 60 nautical miles, or one minute of arc equals one nautical mile. The distance in degrees between points B and C is just 0° 60′, which is equal to 60 nautical miles. A clear understanding of the method of using the chart is absolutely essential, for it forms part of the daily routine of a navigator. The method of finding the ship's place on the chart by soundings will be discussed later, in connection with a practical example. For further examples of ways in which to use the chart the student is referred to any of the books already mentioned.

THE SAILINGS.

The principles underlying this subject should be clearly understood, as they will make the remaining portion of the study of navigation much more readily understood, particularly the last of this book.

In considering the position of a vessel at sea, with reference to some other place which she has left or to which she is bound, the following must be considered:

The Course.
Distance.
Difference of Latitude.
Departure.
Difference of Longitude.

Here two cases arise: The first, a vessel goes on a known course and through a known distance from a place whose latitude and longitude are also known, to another place whose latitude and longitude we wish to know. The second, the latitude and longitude of two places being known, it is required to find the course and distance from one to the other.

Plain Sailing is sailing on the supposition that the earth is flat; that the meridians are straight lines parallel to each other and at right angles to the equator. This is of course not true but is sufficiently accurate when very small portions of the earth's surface are considered.

For example, let us suppose a ship to be at A, Fig. 8, and proceeding along A S to S; then A S is the distance in nautical miles (given by the log, see page 27), A N is the departure, N S is the difference of latitude and the angle A S N is the course. Now if any two of these quantities be given, the remaining two can be found by simple trigonometry, or by solving a right triangle. In order to simplify this work Tables I and II in Bowditch's Navigator are used, Table I to be used if the course is in points or fractions of a point, Table II when the course is given in whole degrees.

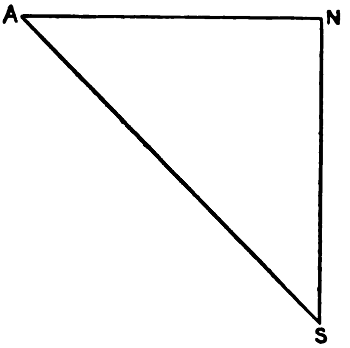


Fig. 8.

Example: A ship is in long. 56° 24′ W and lat. 41° 3′ N at noon on Jan. 1, 1900, and from this position sails 142 nautical miles (given by the log) on a SE by S true course; find the difference of latitude and the departure. In Table I under 3-point courses (SE by S being a 3-point course, as previously explained,) we look up the difference of latitude and departure corresponding to 142 miles distance, and we find diff. lat. = 118.1 miles and the dep. = 78.9 miles. As we have been going in a southeasterly direction, both our lat. and long. have been decreasing. Tables I and II, often called traverse tables, can be used also for solving right triangles.

Parallel Sailing. By this we mean sailing either due east or west. In this case there is of course no difference of latitude and the distance sailed is the departure. Now if we change this departure from miles to difference of longitude in degrees, minutes and seconds we can at once prick off our position on the chart.

Suppose a ship in lat. 52° N to sail 79 miles due west, the difference of long. is found as follows:

Lat. 52°	Log. sec.	52° = 10.21066
Dep. 79	log.	79 = 1.89763
Log. of Diff. of Long.		= 2.10829

rejecting tens in the index, number corresponding to log 2.10829 = 128.3, which is equal to 2° 8′ 18″, which is the difference of longitude in degrees. Tables I and II may be used for the same purpose, as follows: With latitude as a course and departure in the latitude column, the difference of longitude in minutes is found in the distance column. For instance, in the previous problem take the course as 52°, and use Table II for 52° and we find in the distance column 129 opposite 79.4; in the latitude column $129' = \frac{129'}{60} = 2° \ 9'$ difference of longitude. We might have interpolated in the table, and arrived at the same result as before, namely, 2° 8′ 18″.

Traverse Sailing is merely an extension of the method of plain sailing; and if the plain sailing problem is understood, no trouble will be experienced with traverse sailing.

Mercator's Sailing. First turn to page 15 and read description of Mercator's chart.

The latitude and longitude of two places being known, required to find the course and distance between them: Find the difference between the two latitudes, and reduce it to minutes by multiplying the degrees by 60, etc. Name the difference north or south according to direction in sailing from one place to another. From Table III find the meridional parts due to each latitude and treat them in the same manner as the latitudes, taking their difference or their sum, as the case may be, and call this the meridional difference of latitude. Find the difference of longitude, and name it E or W as the case requires.

Find the logs of the difference of longitude, of the true difference of latitude and of the meridional difference of latitude, from Table 42, Bowditch. Now from the log of the difference of longitude subtract the log of this meridional difference of latitude, and the result is the log tangent of the course. Look up the angle corresponding to this log tangent in Table 43 ; this gives the course. Also in Table 43 find the log secant of the course, and add this to the log of the true difference of latitude, and the number corresponding to this sum is the distance. For a more complete account see Bowditch, pages 49–53. The following example may help make the problem clear:

Find by Mercator's sailing the course and distance from Cape Cod lighthouse, in latitude 42° 03′ N, longitude 70° 04′ W, to the Island of St. Mary, one of the Western Islands, in latitude 26° 59′ N and longitude 25° 10′ W.

L_1 = 42°	03′ N.	Merid. Parts	2770.4	Lo_1	70°	4′	W.
L_2 36°	59′ N.	" "	2377.6	Lo_2	25°	10′	W.
5°	4′	m =	392.8		44	54′	

Diff. Lat. = 304′ D. Lo. 2694′

Diff. Lo. = 2694 log. 3.43040
m = 392.8 log. 2 59417

0.83623 ≐ log tangent

Table 42 log. tan. 0.83623 = 81° 42′ = Course

Diff. Lat. = 304′ log. 2.48287
log. sec. 81° 42′ = 0.84056

log. 3.32343 = 2,106 miles dist.

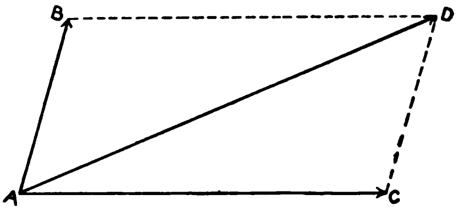
True Course, S 81° 42′ E.
Distance, 2,106 miles.

Formulæ by which all possible cases of Mercator's sailing may be solved are tabulated on page 50, Bowditch.

Great Circle Sailing. The shortest distance between two points on a sphere is along the great circle passing through the points. The simplest way of finding the Great Circle Course is to stretch a string from one point to the other on a globe, note the latitude of the points at which the string cuts the different meridians, and mark upon the chart the positions thus found. Join these points, and you have the course. It is necessary to steer from point to point in order to come nearest to the most direct path between places. On long voyages, such as a trans-

Atlantic or trans-Pacific trip, a great circle track is considerably shorter and is usually taken by steamers. Sailing vessels may find great circle sailing very useful, not only in indicating the shortest distance between two places, but also as showing which is the best tack if the course cannot be laid before the wind. The tack which will keep the vessel nearest to the great circle will be the gaining tack; it may happen that what is apparently a losing tack is in reality a gaining one. Great circle sailing is applicable mainly to steam vessels, for they can generally keep any course desired.

Current or Oblique Sailing. A current is a body of water flowing steadily in a certain direction. The *set* of a current is the direction in which it moves; the *drift* is the rate at which it moves in a specified length of time, as, for example, so many knots per hour. When a ship sails with a current her motion is increased by an amount equal to the drift of the current; when sailing against a current her speed is diminished by an amount equal to the drift. When sailing obliquely to a current a ship's motion is increased if the direction of the current is from abaft the beam, and decreased if from forward of the beam.

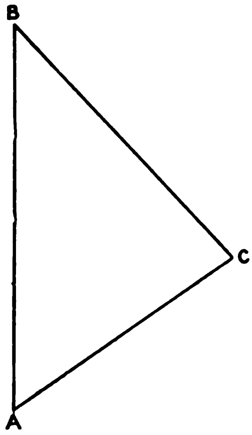


The true course of a vessel sailing in a current is the diagonal of a parallelogram, in which the drift and set of the current in a certain time, and the course steered and speed in the same time, form the adjacent sides. However, in case the set of the current and the course steered are in the same straight line, the current will not affect the course. A simple illustration will show how to find the course if the current is across the path of the ship. Let A be a ship's position, A C the direction of the course steered, and also let A C be the distance in miles the vessel will travel in an hour; further, let A B be the drift and set of a current. Complete the parallelogram A B D C, and the diagonal A D gives the course made good and the distance sailed in one hour.

This is never used when in deep water. The reverse of the above problem is worked at noon each day when in open ocean, to find the set and drift of the ocean currents. However, in coasting, and where known currents exist, the above may be useful.

Navigating the Ship. *Taking the Departure.* Upon clearing the land, the first step before shaping the course and commencing the log is to fix the ship's position or to take the departure. The position of the ship may be referred to some known point of land, lighthouse, or any prominence whose latitude and longitude are tabulated. The latitudes and longitudes of such places all over the world are tabulated in Table 49, Bowditch.

Departure by a Single Bearing and Distance. Get the compass bearing of the point or lighthouse, and reverse the bearing; this reversed bearing is entered or set down as the first course, subject to the same compass corrections as all compass courses, as previously explained. The distance of the ship from the object, to be estimated by the navigator, is taken as the distance run; this latter is of course somewhat inaccurate, but ordinarily will suffice. The bearing of the object is reversed in order to get the course of the ship, for suppose a light was found to bear by compass NW, then the ship is in a SE direction from the lighthouse. A more accurate method is to take two bearings of the same object; for example, if a ship's track lay so that the object will remain in view for a time, take the bearing of the object and note the angle between it and the direction of the ship's head. After the ship has run on the same course far enough to change the bearing of the object a few points, note again the angle between the bearing of the object and the direction of the ship's head. In the following figure let C be a point of land, and let A be the first position of the ship and B the second; the angle C A B and C B A is obtained as noted above, and the side A B of the triangle is the distance the ship has run between the times of taking the bearings. We may find the necessary distance A C or B C by plane trigonometry, as follows:



$$\mathrm{AC} = \frac{\mathrm{AB}\ \mathit{Sin}\ \mathrm{CBA}}{\mathit{Sin}\ \mathrm{ACB}}$$

$$\mathrm{BC} = \frac{\mathrm{AB}\ \mathit{Sin}\ \mathrm{BAC}}{\mathit{Sin}\ \mathrm{BCA}}$$

For example, when the ship was at A it was running ENE; after running 25 miles N by W it bore SE: required the distance of the ship from the point of land C at the time of the last bearing at B.

$$\begin{aligned}
\mathrm{AB} &= 25\\
\mathrm{BAC} &= 7 \text{ points} = 78^\circ\ 45'\\
\mathrm{CBA} &= 3 \text{ points} = 33^\circ\ 45'\\
\mathrm{ACB} &= 6 \text{ points} = 67^\circ\ 30'
\end{aligned}$$

$$\begin{aligned}
\log 25 &= 1.39794\\
\log \mathit{sin}\ \mathrm{BAC} &= \frac{9.99157}{11.38951}\\
\log \mathit{sin}\ \mathrm{ACB} &= \frac{9.96562}{1.42389}, \text{ which corresponds to } 26.5\\
\therefore \mathrm{BC} &= 26.5 \text{ miles.}
\end{aligned}$$

For further examples see Bowditch, pages 61 and 62.

Shaping the course. Having taken the departure, the course must then be shaped, whether by rhumb or by great circle. The true or magnetic course may be taken from the chart; if the magnetic course be taken, allowance must be made for the deviation for that direction of the ship's head to obtain the compass course. If sailing in a known current, proper allowance for it should be made. Should the wind be ahead, the tack must be chosen upon which the greatest distance will be made good toward the point of destination; this latter must be altered, however, should there be any outlying shoals.

The day's work is the operation of computing from the data expressed in the log-book the ship's run for twenty-four hours preceding each noon. The term is usually restricted to the dead reckoning, and the data given are the latitude and longitude at the preceding noon (by observation), the compass courses, the distance run on each course (given by the log), compass variation, compass deviation for each direction of the ship's head, the leeway, the set and drifts of currents if they are known, the force and direction of the wind, state of sea, sail carried, etc. This data is recorded to find the latitude and longitude by dead reckoning, the true course made good, and the compass bearing and distance of the port of destination, or that point toward which the ship is to be directed during the coming twenty-four hours.

Strictly speaking, the day's work includes all the computations the navigator must make each day, the results of which are entered in the log-book. In sailing vessels the mate keeps the log-book and the position of the ship by dead reckoning. Dead reckoning is merely the application of the problems already laid down; for instance, if the ship's position is known at noon on a certain day, and during the following twenty-four hours it has run a certain number of miles on a certain compass course, the position at noon on the next day is found as follows: First correct the compass course for variation, deviation, leeway and known currents, to find the true course made good; then in Table I or II, (depending upon whether the course is given in points or degrees) under the distance run, find the latitude made good and the departure. We may change this departure into difference of longitude, as indicated by example in parallel sailing. By applying our difference of latitude and difference of longitude to our position on the preceding day, we get our new position. This method of finding the ship's position is called dead reckoning. On making the land the navigator is aided in his dead reckoning by the lead line, which gives another clue to the ship's position.

Making the Land. Every precaution and forethought should be observed as the ship draws near the land, and the careful navigator will be on the lookout for the many evidences of the proximity of the land, such as the shoaling of the water, the change of color of the water, the change of temperature of the surface water, the presence of land birds, etc. As soon as land is made, the ship's position should be marked off on the chart by reckoning and verified by bearings of well-defined points, if any are in view. An easy and satisfactory method of finding position on making land is to take sextant angles of any well-defined prominent points, which, when used in connection with Lecky's "Off Shore Danger Angles," gives the distance in miles from the point of land to the ship, and by also observing the bearing of the point the exact position of the ship may readily be established.

It is always a good plan to make land, if it can be done without going too far out of one's way, to get a line on the chronometers which may or may not have changed their rate. A change in rate of the chronometer or other errors, which will affect the ship's position materially, may thus be ascertained, and should thick weather come on later, the navigator would be in a better position to take the ship safely to her port or destination. Again, should there be any doubt as to longitude, and it was found impracticable to make any point of land, it may be best to make the latitude of the place required and then if possible run on a parallel. The safe way is to locate the ship on a Sumner's line and know to a certainty the relative bearing of the land, which will determine the course; should thick weather be immediately threatening and close in, the navigator would at least know where he is and whether or not danger was near. Of course due regard should always be given to soundings, and even in working your way into an unknown harbor in clear weather, soundings are of infinite value to the navigator. Sumner lines, chronometers, etc., will be taken up shortly and fully explained; also the currents, the time of tide, as well as other facts laid down in the sailing directions, must be considered.

The Method of Sounding. Sounding is the operation of finding the depth of water and the nature of the bottom by means of a lead weight. Two leads are used for sounding,— a hand lead weighing from 7 to 14 pounds, with a line marked to 20 fathoms, and a deep sea lead weighing from 40 to 100 pounds, with a lead line about 100 fathoms in length. A hand lead weighing about 10 pounds is about all one man can easily handle, and is of use only in shallow water; as, for instance, in making a harbor. If the ship is making 7 knots or more, it takes a good leadsman to get bottom with a hand lead in 10 fathoms.

Deep sea leads, as the name implies, are for getting soundings in deep water. It is necessary when using an ordinary deep sea lead of about 40 pounds to heave the ship to; previous to heaving to, the line is reeled off until there is sufficient amount of loose line to reach bottom, and the lead carried forward. The cavity in the bottom of the lead is filled with grease or soap, which catches and retains a sample of the bottom.

Deep sea sounding in this manner is a clumsy operation, and at present is but seldom used. An improved method is the use of

Lord Kelvin's Patent Sounding Machine, shown in Fig. 9. Piano wire wound on a drum is used for the lead line; this makes it possible for the lead to descend much quicker. With this machine it is claimed that bottom can be reached at 100 fathoms, with the ship making 14 knots or more. A glass tube descends with the lead; this tube is hermetically sealed at the top end and open at the bottom. The interior of the tube is covered with a chemical preparation, which changes color when salt water touches it. As the lead sinks deeper and deeper, the pressure becomes greater and greater, and the air in the tube is compressed as the salt water is forced in. The discoloration of the chemical shows exactly how high the water rose in the tube, and the depth found by means of the scale (graduated to fathoms) attached to the side of the tube. In addition there is a small hand moving over a dial, which also indicates the amount of wire unwound.

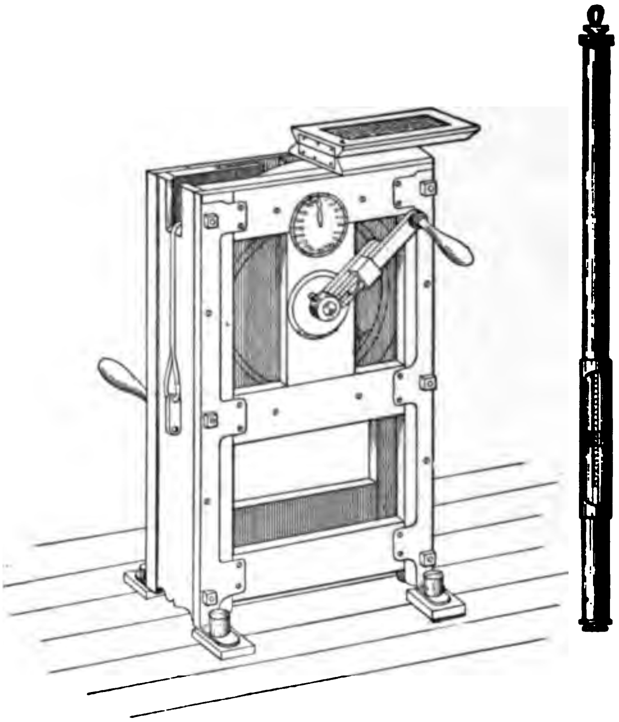


Fig. 9.

For purposes of navigation no importance can be placed upon a single cast of the lead; the proper method to follow in sounding is as follows: Take soundings at regular intervals, say every 4 or 5 miles; mark a strip of paper so that the distance between the marks is 4 or 5 miles, as the case may be, using of course the chart best suited for the purpose, from which the 4 or 5 mile intervals may be taken. Now as each successive cast is made, the depth and nature of the bottom should be marked on the strip of paper, thus obtaining a series of soundings. The bit of paper will resemble Fig. 10. Now with this strip of paper move about the chart in the locality where the vessel is thought to be, and have the edge of the paper run or point in the same direction as the ship is steering true. The soundings on the paper will be found to approximate those on the chart, some places much more closely than others. It requires experience and practice to decide just where the ship is, particularly if it has been running on dead reckoning for several days. Of course in continued thick weather it is more difficult to be absolutely sure of your position by soundings, but nevertheless they are valuable, and may prove that you are not where you think you are.

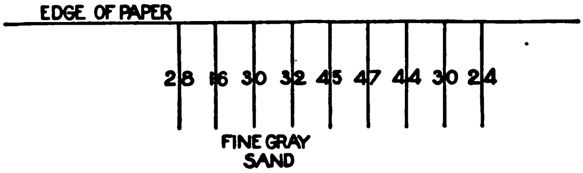


Fig. 10.

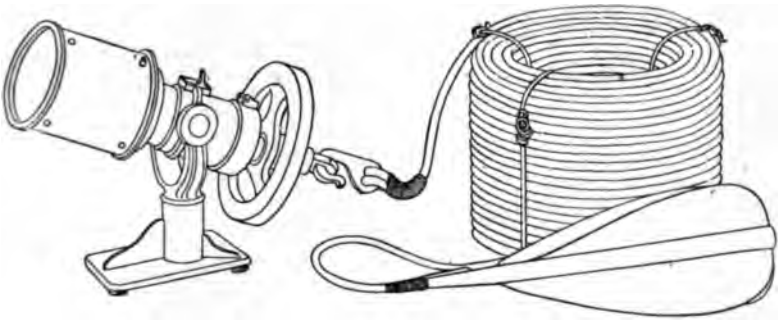


Fig. 11.

Taffrail Log. This form of log is now in common use, and shown by Fig. 11. A description will not be given, as it may be found in most books on Navigation and in catalogues; suffice it to say, that the number of knots and tenths of knots are indicated on the dial, and the ship's speed or distance made, ascertained.

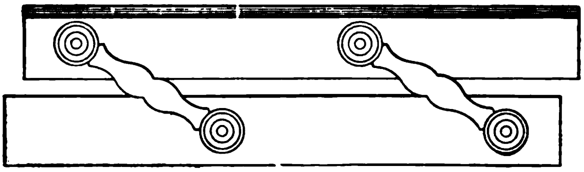


Fig. 12.

The Parallel Rule is shown in Fig. 12; it is used to transfer the direction of lines from one place on the chart to another, as explained in the paragraphs on finding positions, etc., on the chart.

The Horn Protractor, shown in Fig. 13, has to some extent displaced the parallel rule. A form of horn protractor marked in points and degrees, with a long string and hand, as in the figure, is much easier to use than a parallel rule, which at best is troublesome. The object of the string and hand is this: by moving the hand so that the angular distance between it and the string is equal to the correction to be applied to the true course in order to get the compass course, and by observing the index hand we get the compass course to be followed in order to make good the true course. A little practice in the use of one of these patent course finders will reveal their possibilities much easier than they can be described.

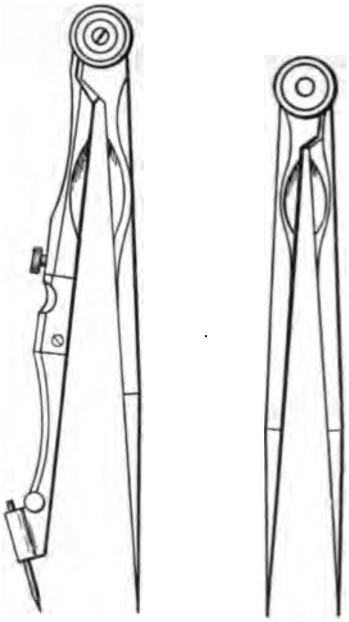


Fig. 14.

Dividers are used for picking off distances upon the chart. It is advisable to have two pairs,— one with both legs metal and one with a pencil point, as shown in Fig. 14.

A word in regard to lead pencils: avoid if possible round pencils; they will be constantly rolling off the chart table at sea, and will thus cause annoyance; either hexagonal or triangular pencils should be used.

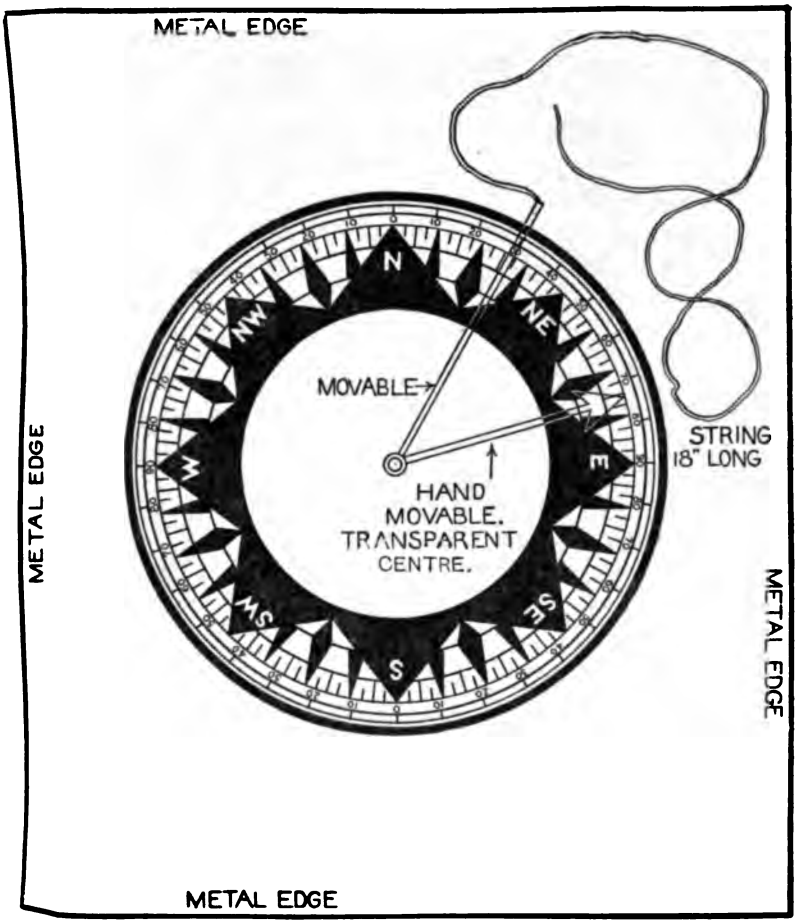


Fig. 13.

The following is taken from Lord Kelvin's "Lecture on Navigation":

"When no landmarks can be seen, and when the water is too deep for soundings, if the sky is cloudy so that neither sun nor stars can be seen, the navigator, however clear the horizon may be, has no other way of knowing where he is than the dead reckoning and no other guide for steering than the compass.

"We often hear stories of marvellous exactness with which the dead reckoning has been verified by the result. A man has steamed or sailed across the Atlantic without having got a glimpse of the sun or stars the whole way, and has made land within five miles of the place aimed at. This may be done once, and may be done again, but must not be trusted to on any one occasion as probably to be done again this time.

"Undue trust in the dead reckoning has produced more disastrous shipwrecks of seaworthy vessels, I believe, than all other causes put together.

"All over the surface of the sea there are currents of unknown strength and direction. Regarding these currents, much most valuable information has been collected by our Board of Trade and Admiralty, and published by the Admiralty in its 'Atlas of Wind and Current Charts.' These charts show, in scarcely any part of the ocean, less than ten miles of surface current per twenty-four hours, and they show as much as forty or fifty miles in many places. Unless these currents are taken into consideration, then the place of the ship, by dead reckoning, may be wrong by from ten to fifty miles per twenty-four hours, and the most accurate information which we yet have regarding them is, at the best, only approximate. There are, in fact, certain currents of ten miles and upwards per day, due to wind (it may be wind in a distant part of the ocean), which the navigator cannot possibly know at the time he is affected by them.

"I believe it would be unsafe to say that, even if the steerage and speed through the water were reckoned with absolute accuracy in the 'account,' the ship's place could in general be reasonably trusted to within fifteen or twenty miles per twenty-four hours of dead reckoning. And, besides, neither the speed through the water, nor the steerage, can be safely reckoned without allowing a considerable margin for error.

"Consider further the steerage. In a wooden ship a good ordinary compass, with proper precautions to keep iron from its neighborhood, may be safely trusted to within one-half quarter point; but reckoning the errors of even very careful steering by compass, we cannot trust to making a course which will be certainly within a quarter of a point of that desired. Now you know an error of a quarter of a point in your course would put you wrong by one mile to the right or left of your desired course for every twenty miles of distance run. Thus, in the most favorable circumstances you are liable through mere error of steerage by compass, to be ten miles out of your course in a run of only two hundred.

"In an iron ship, if the compass has been thoroughly well attended to as long as the weather permitted sights of the sun or stars, a very careful navigator may be sure of his course by it within a quarter of a point, when cloudy weather comes on; but by the time he has run three or four hundred miles, he can no longer reckon on the same degree of accuracy in his interpretation of its indications, and may be uncertain as to his course to an extent of half a point or more until he again gets an azimuth of sun or star.

"No doubt an exceedingly skilful navigator may entirely, or almost entirely, overcome this last source of uncertainty when he runs over the same course month after month and year after year in the same ship; but it is not overcome by any skill hitherto applied to the compass at sea when a first voyage to a fresh destination, whether in a new ship or an old one, is attempted.

"All things considered, a thoroughly skilled and careful navigator may reckon that, in the most favorable circumstances, he has a fair chance of being within five miles of his estimated place after a two-hundred-mile run on dead reckoning; but with all his skill and with all his care, he may be twenty miles off it; and he will no more think of imperilling his ship and the lives committed to his charge on such an estimate, than a skilled rifle-shot would think of staking a human life on his hitting a bull's-eye at five hundred yards.

"What, then, do practical navigators do in approaching land after a few days' run on dead reckoning? Too many, through bad logic and imperfect scientific intelligence, rather than through conscious negligence, run on, trusting to their dead reckoning.

"At last the fatal time comes: the navigator has trusted to his dead reckoning once too often; he has made a 'center' not a 'bull's-eye,' and his ship is on the rocks.

"Every seaman of experience will admit the perfect justice of these remarks, even were they not corroborated by the revelations of the wreck register."

NAUTICAL ASTRONOMY.

The preceding portion of this book has dealt mainly with the methods of finding a ship's position at sea by dead reckoning; this method is of course more or less approximate. In spite of the uncertainty, however, dead reckoning must always be kept, as it is sometimes the only available way of locating the ship.

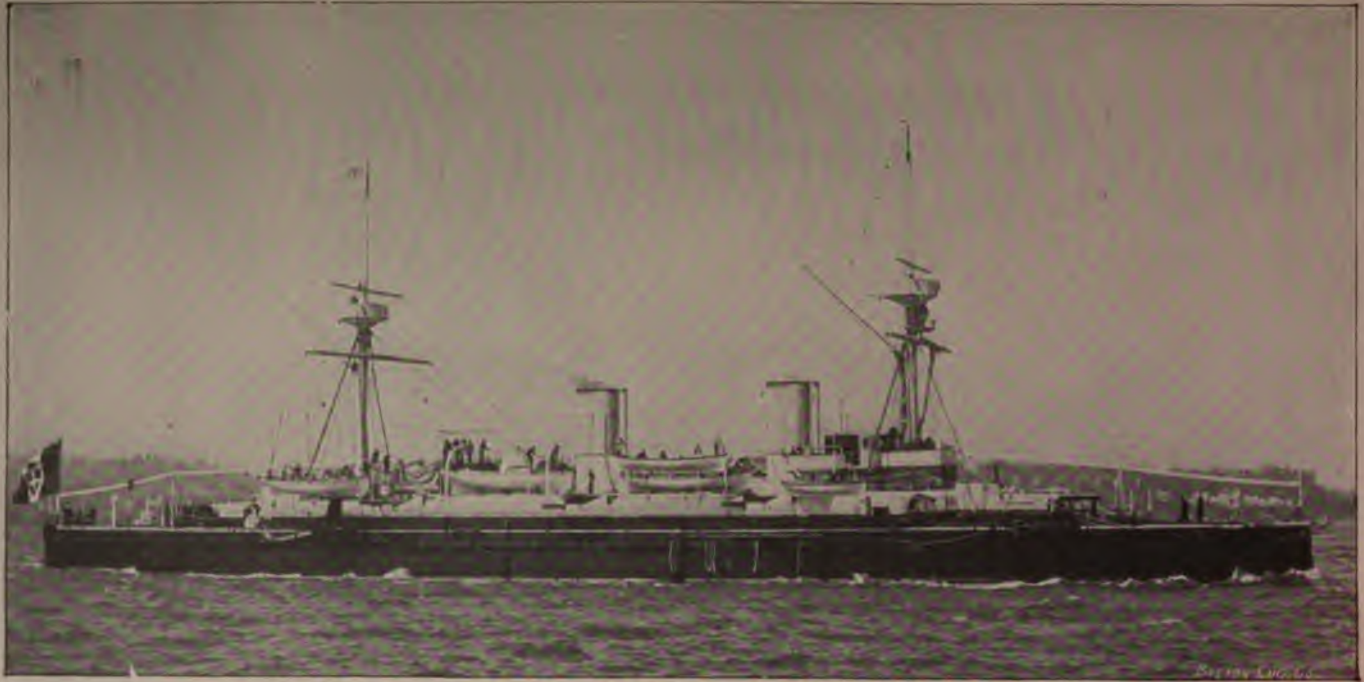
The following portion will be devoted to the branch of navigation which determines the position of a ship by observation of heavenly bodies; this branch is called Nautical Astronomy.

The instruments used in this connection are the Sextant or Quadrant, the Chronometer and the Nautical Almanac. It will now be necessary to give definitions before stating the problems in Nautical Astronomy, previous to reading which the student should reread the definitions given in the first few pages of the book, including those of latitude, longitude, etc.

The following is taken from Norie's "Navigation."

"The Solar System is that assemblage of planets, comets, meteors and cosmical bodies that have the sun as their center luminary, revolving around that body at different distances and with different periodic times.

"The planets of the system, in the order of their proximity to the sun, are: Mercury, Venus, Earth, Mars, the Asteroids, Jupiter, Saturn, Uranus and Neptune. The planets shine by the reflected light of the sun, as do all the bodies of the system; and it is characteristic of planetary motion that a line drawn from the sun's center to a planet would sweep over equal areas in equal times. The inferior planets are the two whose paths are between the earth and the sun; the superior planets move in paths at a greater distance from the sun than the earth's path. A satellite is another name for a moon, and most of the planets in the solar



ITALIAN CRUISER "ÆTNA"

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system are accompanied by one or more such bodies, which revolve around their primary, as a secondary planet. The earth has one moon; Mars two; Jupiter five (the fifth is seldom seen); Saturn eight, and also meteoric rings; Uranus four, and Neptune one or more.

" Comets are luminous bodies whose very eccentric paths lie around the sun.

" Fixed stars are distinguished from the planets inasmuch as their relative positions in the heavens remain the same from year to year. Unlike the planets, which shine by reflected light of the sun, the fixed stars shine by their own light the same as our sun, and are supposed to be the centers of other solar systems. The only fixed stars used in navigation are those of the first and second magnitude. The distances of a few of the fixed stars have been determined; of these distances, none are less than 200,000 times the distance of the earth from the sun. In other words, light travels at the rate of 186,000 miles a second, and it takes eight minutes for the light to come to the earth from the sun; to come from the nearest fixed star α (centauri, a southern star) it would take three years.

The celestial bodies used for navigation purposes and from which data are derived from the Nautical Almanac and Sextant, are the Sun, Moon, Mars, Venus, Jupiter, Saturn and the fixed stars of first and second magnitude. In this book the sun only will be considered,. but the student should understand that the stars are used in practically the same manner as the sun, and if he can use the sun he can also use the stars. There is a feeling current among seamen that there is something mysterious about stars, and that it requires a college education to successfully study them; this is not so. For stellar work in navigation, if one is to study by himself, Lecky's " Wrinkles in Practical Navigation" is doubtless the best book.

Nautical Astronomy. To a person on the surface of the earth the heavens appear like a huge hollow sphere the center of which is the center of the earth. This idea of a large, hollow sphere is more apparent when one is at sea. Only one-half of this sphere is visible to a person on the earth's surface. If a plumb line were drawn through the person and extended far enough in both directions, it would pass through the center of the earth and in the other direction to the surface of the supposed hollow sphere.

Now a surface or plane perpendicular to the plumb line and extending on all sides to meet the concave celestial surface, would divide the hollow sphere into two parts; this plane is called the Rational Horizon. In Fig. 15 let circle E represent the earth and the large circle H Z′ H′, etc., the above-mentioned hollow sphere, or celestial concave, as it is called; let P be the north and T the south pole; T P is then the axis of the earth. P′ or T P prolonged until it cuts the celestial concave is the elevated pole, so called. Let Z be the position of an observer standing upon the surface of the earth; then, as already defined, H H′ is the rational horizon, the circle Q′ Q′ at right angles to the axis T P P′ is the equator on the earth, the celestial equator being Q Q. Hereafter all circles mentioned will be on the celestial concave and not on the earth, although the corresponding circles on the earth, if one cares to consider them, are similar in every respect. For instance, the latitude of a point in the celestial concave is the same as the latitude of a point similarly situated upon the earth. Take point Z on the earth (Fig. 15), and Z′ the similar point in the celestial concave, or zenith point; they both have the same latitude and longitude, because their location is given in degrees, etc., and there are just as many degrees in the arc Q Z′ as there are in arc Q′ Z. As Q Q is the equator, the latitude of Z is the arc Q′ Z or Q Z′ expressed in degrees, minutes and seconds, as defined on page 5. The circle H Z′ H′ N is the observer's meridian. Let S be the position of the sun in the heavens at any given time; let P′ S R M be another meridian passing through the sun's position and making the angle *o* with the observer's meridian; furthermore, let circle Z′ S A N be a great circle, also passing through the sun's position

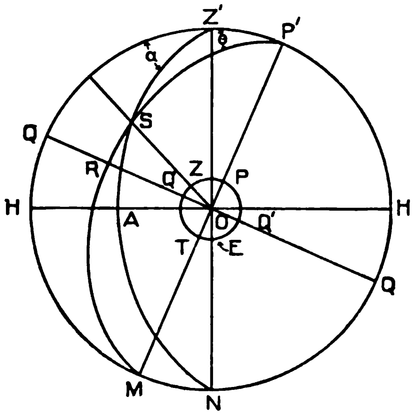


Fig. 15.

S and the zenith Z′, making the angle *a* with the observer's meridian. Angle *o* is called the *hour angle* and the angle *a* the sun's azimuth. Angle *o* is generally expressed in hours, minutes and seconds, and is the apparent time of the observer at Z on the earth (see explanation of time, page 44). Reference to Fig. 16 in connection with Fig. 15 may make these definitions clearer.

Fig. 16 is a view of the celestial concave looking from Z, the observer's position on earth, up to the zenith directly overhead; the same letters are used and refer in both figures (Figs. 15 and 16) to the same points. R S is the sun's declination, or its distance north or south of the equator in degrees, etc. A S is the true altitude of the sun, or its distance above the rational horizon; Q Z′ is the latitude of Z or Z′; the longitude has already been defined. S P′ is the sun's polar distance, S Z′ the sun's zenith distance and Z′ P′ the colatitude of the observer's position at Z. Z′ N in Fig. 15 and Z′ N′, Fig. 16, is the prime vertical or vertical circle passing through the east or west points.

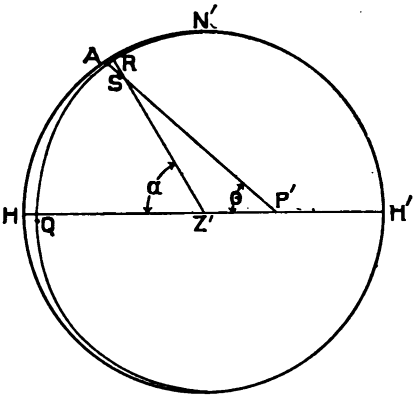


Fig. 16

The student should learn and know what the following terms mean; their use will appear later. They are all essential in the work of navigation, declination, altitude, zenith distance, polar distance, celestial meridian, azimuth, hour angle, colatitude, etc.

Declination is the distance of the sun or any celestial body from the equator, given in the Nautical Almanac (see page 50), for every day in the year.

Altitude is the distance of any celestial body above the horizon, and is measured by a sextant.

Zenith distance is 90° minus the altitude.

Polar distance is 90° minus the declination.

Hour Angle. At three o'clock, for example (or to be more correct, three hours apparent time), the sun's hour angle is three hours; that is, it takes three hours from the time the sun crosses the meridian (which it does at noon) until it reaches the position where its hour angle is three hours.

Colatitude is 90° minus the latitude.

Azimuth of a body is the angle at the zenith between the observer's meridian and the circle of altitude as per Fig. 15; when on the prime vertical the azimuth of a body is 90°.

Amplitude is the arc of the horizon between the point where the sun rises or sets and the east or west point; it is the complement of the azimuth.

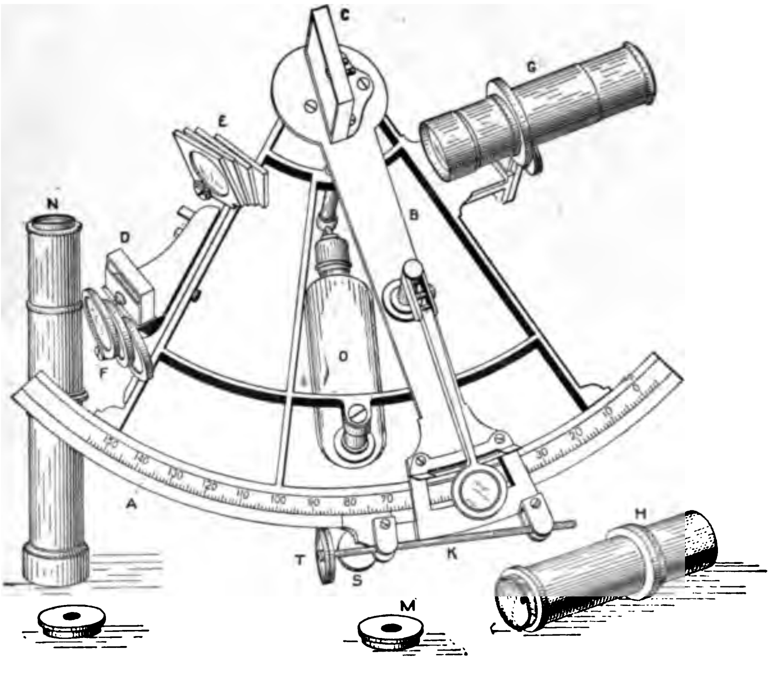
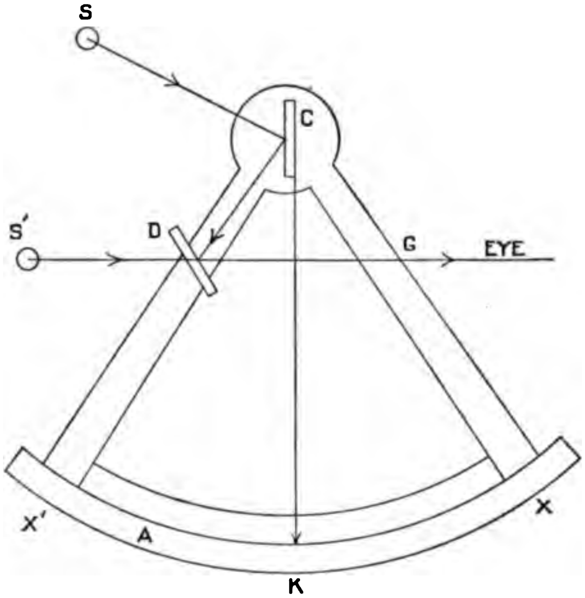


Fig. 17.

The Sextant. This instrument, shown by Fig. 17, is used for measuring angles between two points by bringing the reflected image of one of the points to coincide with the other as seen directly. The frame of the sextant is usually made of brass or gun metal. C is the index glass, D the horizon glass, half of which is silvered. A is the arc, and is divided into degrees, which are generally subdivided to ten minutes; the movable arm B carries at K a vernier by which still finer readings may be had; the verniers are generally divided so that the angle may be read to twenty seconds. G is a telescope which screws into a ring which holds it; N is an inverting telescope which is often used in place of G; H is an eyepiece without lenses, and also screws into the telescope ring; M is a colored eyepiece which goes with the telescope; E and F are colored screens, used when the sun is bright; O is a wooden handle by which the instrument is held.



The principle on which the sextant works is this: If a ray of light suffers two successive reflections in the same plane by two plane mirrors, the angle between the first and last direction of the ray is twice the angle of the mirrors. D is set parallel to C X, and mirror C turns with arm B. The angle between S C and S′ G is twice the angle between the two mirrors D and C; then if the angle X′C X is 60°, the divisions on the scale A in the same length of arc X X′ will be 120°. The use of the sextant is as follows: We wish to find the angle between two points S and S′.

Hold the instrument by the handle and look directly at S′, which is seen through the unsilvered portion of the horizon glass; now move the arm B until point S is seen in the silvered portion of the horizon glass, and the angle between the two objects is indicated at K. This statement is a crude one, and is simply intended to show what the instrument does rather than giving the exact methods of using, which are carefully stated in standard works on Navigation. A few points regarding the instrument are well to know, as every intelligent navigator should be able to "size up" his sextant.

The vernier: When the zero line is in coincidence with a line on the scale, the terminal line should also be in coincidence with another line on the scale; furthermore, in every well-cut arc only one line on the vernier appears to coincide with a line on the scale.

It is not advisable to lay a sextant down in the hot sun; the metal of the arc being different from that of the sextant frame, unequal expansion takes place and may result in a permanent distortion of the divided arc, thus destroying the accuracy of the sextant.

The horizon glass should be perpendicular to the plane of the sextant, as should the index glass, also. The line of sight of the telescope should be parallel to the plane of the instrument. If there were no index error, the zero or first graduation on the scale should coincide with the first mark on the vernier. Index error is common, and can be found roughly by making the image of the sea horizon coincide with the horizon itself as accurately as possible. If the zero of the index is at zero on the scale there is no index error, but if it is on the arc the correction is so much subtractive, or when off the arc is so much additive. A better way to do it is to measure the sun's horizontal diameter; as this method is explained in any good book on navigation, it will not be given here. The common use of the sextant is to get altitudes of heavenly bodies, to measure heights and to measure angles or the distances between points in general.

When a sea horizon cannot be obtained, that is, when a ship is in port, the altitude of a body can be found by using an *artificial horizon* (which consists of a saucer of quicksilver or molasses) instead of depending upon a sea horizon. The process consists in bringing the image of the sun down to the image reflected from the artificial horizon. The altitude observed in this way is twice the apparent altitude.

Perhaps the best method for a novice to pursue in observing an altitude, is to start with arm B, at zero and look directly at the sun; both the real sun and its reflected image will appear in the horizon glass D; now slowly bring the instrument down until the sea horizon is seen in the horizon glass, moving arm B at the same time, keeping the sun's reflected image in the horizon glass; when the lower limb of the sun is about to touch the horizon, clamp the arm B by the screw S, and to get the final contact between the sun's limb and the horizon turn the tangent screw T. Practice makes perfect; this is true of taking altitudes or in using the sextant generally. Personal instruction by some one familiar with the use of the instrument will enable one to get reliable observations sooner than by stumbling along alone.

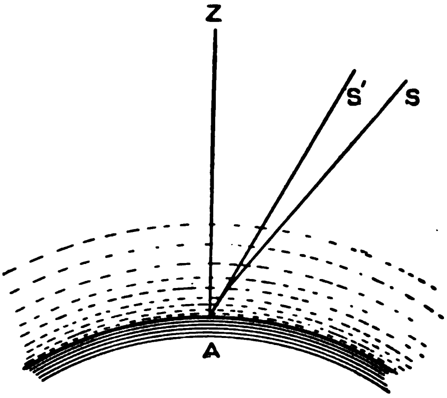


Fig. 18.

True Altitude. The altitude of a celestial body as read off a sextant is not the true altitude, but is subject to corrections. First comes the index *error* of the sextant, which has been explained; the next is *dip*, which allows for the height of the eye above the surface. Table 14, Bowditch, gives the dip correction for varying heights of eye; dip is always a subtractive correction.

Refraction. Owing to the atmosphere which surrounds the earth, the sun's rays are bent, as indicated by Fig. 18; hence, to a person standing at A and looking at the sun, which is really at S, it appears to be at S′. Refraction is a subtractive correction, and is found in Table 20, Bowditch, it depends upon the altitude of the body and the density of the atmosphere (height of the barometer).

Parallax **is due to the fact that we observe the sun from the earth's surface and not from its center.** To an observer on the **earth the sun appears in the direction** B **S, Fig. 19, but its direction from the center of the earth** is **O S, hence as we are reducing the observed altitude to the true altitude we must correct for parallax an additive** correction, which is the angle **B S O, and is given in** Table 16, Bowditch.

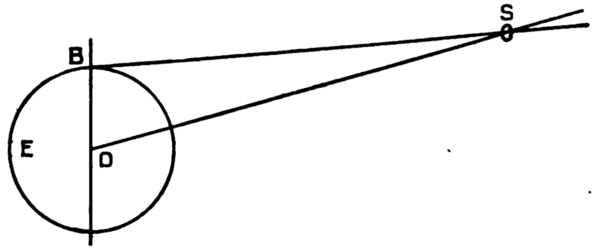


Fig. 19.

Semidiameter of a celestial body is half the angle subtended by the body's diameter. This is an additive correction if the lower limb is used, and gives the altitude of the body's center; this correction is given in the Nautical Almanac.

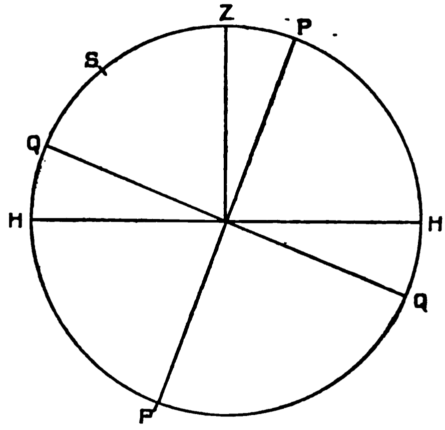


Fig. 20.

Finding Latitude. When the body observed is on the meridian its altitude ceases to change, and the most convenient way of finding the latitude is by observing a meridian altitude. Referring to Fig. 20 let H Z H, etc., be the celestial concave, Z the zenith, P the elevated pole, S the position of the sun or other celestial body, Q Q the celestial equator, and H H the rational horizon.

First let us see what we know: we can get the declination Q S of the sun or other bodies, from the Nautical Almanac; we can also get H S, the true altitude, by correcting an observed altitude made with a sextant. The latitude we are after is the arc Q Z; we know that A Z is 90 degrees, as the zenith is 90 degrees from the horizon, therefore S Z is equal to 90 degrees — S H = 90 degrees — true altitude, and is called zenith distance. Furthermore, Q Z = latitude = Q S + S Z = declination + zenith distance. A concrete case will illustrate this. The student is also referred to a sample page from the Nautical Almanac at the back of the book.

At sea, May 3, 1902, long. 45 degrees W. obs. meridian, alt. sun's lower limb (⊙) 56 degrees 10′, sun bearing south, index corr. + 2′ height of eye 20 feet: required the latitude.

44.5		Decl.		15°	28′ N
3		Corr. 45° W			+2′
133.5″ = 2′ +		Red. Decl.		15°	30′ N
Index Corr.	+ 2′				
Semidiam.	+ 15′ 53″	obs. alt.	56° 10′		
dip	—4′	corr.	+ 13′		
refraction	—1′	true alt	56° 23′		
		zenith dist.	33° 37′	33°	37′ N
parallax	+ 5″	latitude		49°	7′
	+ 18′ — 5′				

Take the sun's declination from the Nautical Almanac for noon of the day and correct it for the longitude, because the given declination is for the Greenwich mean noon. The hourly difference is also found in the Nautical Almanac; remember that 15 degrees of longitude is the same as one hour; add the hourly difference if the longitude is west, subtract if the longitude is east. Correct the observed altitude for index error, dip, refraction, semidiameter and parallax, and subtract it from 90 degrees to get zenith distance. When the observer is north of the sun call the zenith distance N, when he is south of the sun call it S. When the declination and zenith distance are of the same name take their sum; when of opposite names, take their difference — the result is the latitude. When the declination and zenith distance are of the same name, the latitude is also of that name, when of different names the latitude takes the name of the greater. In low latitudes the sum of corrections for dip, parallax, semidiameter and refraction is practically + .12′; therefore, if we subtract the sextant altitude from 89 degrees 48′ or 90 degrees minus 12′, we get the same result as if we added 12′ to the correct sextant reading and then subtracted from 90 degrees. This practice of subtracting the correct sextant reading from 89 degrees 48′ to get zenith distance is common in sailing vessels; it should, however, not be used in high latitudes or low latitudes; in fact, until one understands the nature of the corrections, it is best not to use 89 degrees 48′, but to apply each correction separately. If the correction for parallax is left out (in the case of the sun or fixed stars) no serious error will be introduced.

Latitude by Reduction to the Meridian. The following concise explanation is taken from Raper.

"When the sky is cloudy, or the weather variable, the sun or any other celestial body, though obscured when exactly on the meridian, frequently appears for short intervals of time, both before and after the meridian passage. When the body is near the meridian, the change of altitude in a small portion of time is very small, and though the altitude near the meridian changes at a different rate in different latitudes, yet the change of altitude in a given small interval is not sensibly affected by a change of several miles in the latitude, and therefore it may be computed with tolerable accuracy, even when the latitude by account (which is used in the computation) is considerably in error. If, accordingly, at the time of observing an altitude near the meridian, we know the hour angle, we may find very nearly by computation the difference of altitude by which to reduce the observed altitude to the meridian altitude, and which is thence called the Reduction to the Meridian."

"This method is, in point of simplicity, but little inferior to the meridian altitude, to which it is next in importance; and it particularly demands the attention of seamen, because, when the latitude by observation is left, as it too generally is, to the casualty of obtaining the meridian altitude, it is frequently lost for the day."

"The term 'near the meridian' implies a meridian distance limited according to the latitude, the declination, and also to the degree of precision with which the time is known."

The rule for these limits is as follows: The hour angle of the sun, or the time from noon, should not exceed the number of degrees in the sun's meridian zenith distance. For instance, if the sun's meridian altitude be about 75 degrees, the time from noon of taking the ex-meridian should not be greater than fifteen minutes, but better less.

The computation. Take an altitude of the sun and note the time. Find the sun's hour angle, or the time from noon; thus, when the apparent time has been lately determined, that is, by the time sight in the morning (see discussion on time, page 46). If the ship has made westing, subtract the difference of longitude made good from the apparent time found; if easting has been made, add the difference of longitude to the apparent time, the result is the apparent time required.

If the apparent time has not lately been found by observation, the apparent time may be found from the chronometer, using the longitude by account, thus: To the G. M. T. (Greenwich mean time) given by the chronometer (after applying the gain or loss up to the time) reduce the equation of time (Nautical Almanac) and apply it to the G. M. T. as indicated in the Nautical Almanac. The result is the Greenwich apparent time. If the longitude is west, subtract this longitude in time from the G. A. T. (Greenwich apparent time), or if east add it, and the result is the apparent time at ship.

Find the declination of the sun, and correct the altitude for dip, semidiameter, parallax and refraction and index error. Add together the logarithm from the table, Bowditch, and the log, sine square of the hour angle; the sum is the log sine of the reduction. Add the reduction to the true altitude, and the result is the meridian altitude at the place where the meridian altitude was observed; use this meridian altitude to find the latitude of the ship as previously indicated. The latitude thus found is the latitude of the place where the observation was made, and not at noon; to get it from noon we must use Tables I and II, Bowditch, taking into account the course made good and the distance run during the time between the observation and noon at ship.

Example: Latitude by account 47 degrees N, longitude by account 25 degrees W at 11 minutes 48 seconds before noon, corrected altitude of sun 63 degrees 54′, reduced declination 17 degrees 4′N, find the latitude.

Lat. 47° decl. 17° (both N) 0.416
11m 48s sine sq. 6.821
log. sine of reduction = 7.237 red. = 0° 6′
alt. 63° 54′
mer. alt. 64° 0′

90° 0′
64° 0′ merid. alt.
26° 0′ N zenith dist.
17° 4′ N Declination
43° 4′ N Latitude 11m 48s before noon at ship.

The Chronometer. This is a watch constructed as nearly perfect as possible; it is furnished with an apparatus by which the changes of rate due to expansion or contraction, by heat or cold, are nearly obviated. Chronometers should receive great care and be placed in a position where no jars or shocks are likely to be experienced, as these will often change the rate. This instrument gives Greenwich mean time (when the correction is applied) and is, of course, a factor in the determination of longitude.

A chronometer which has a regular rate, that is, gains or loses the same amount every twenty-four hours, is satisfactory, but when this rate varies and no dependence can be put upon it, the instrument is of little or no value. Chronometers often change their rates, that is, after going for some time gaining or losing a certain amount each day, they gain or lose another amount for a while. The navigator should watch his chronometers carefully and compare them (if two or more are on board) every day; further, should any points of land or islands come in sight, so that the ship can be located by bearings of the shore, the chronometer error can be ascertained (this will be taken up later).

Relation of Longitude (Arc) to Time. The following will show just how the chronometer is the agent by which we find our longitude. The circumference of every circle is divided into 360 equal parts or degrees; now the earth, whose circumference is a circle, is 360 degrees, turns on its axis in the direction of this circumference once in 24 hours; therefore the 360 degrees of circular measure are the equivalent of 24 hours; dividing 360 degrees by 24 we get 15, hence 15 degrees of-arc are the equivalent of one hour. We say, astronomically, that as a complete rotation of the earth upon its axis is performed in 24 hours, meridians 15 degrees apart are thus brought to the sun at regular intervals of one hour.

In circular measure	(arc)	In Time
360 degrees	=	24 hours
15 "	=	1 hour
1 "	=	4 min.
15′	=	1 min.
1′	=	4 sec.
15″	=	1 sec.

By means of this table we can change longitude into time, or time into longitude.

Time. The instant that a body is on the meridian of the observer, it is called its transit or culmination. A body is, in the course of one complete turn of the earth, on the meridian twice; when on the meridian directly over the observer's head it is called the upper transit; when underneath, the lower transit.

Solar Time is measured by the daily motion of the sun, and is called apparent time. Apparent time is the hour angle of the center of the actual sun.

The Apparent Solar Day is the time between two successive upper transits of the sun. When the sun is on the observer's meridian, it is *apparent noon* at that place.

The apparent day varies in length from two causes: *first*, the sun does not move in the equator but in the ecliptic, the plane of the ecliptic making an angle with the plane of the equator equal to the inclination of the earth's axis; *second*, the sun's motion in the ecliptic is not uniform. At times the sun moves over an arc of 57′ of the ecliptic in a day, and at other times over an arc of 61′ in the same time.

Thus apparent time cannot be taken as a standard, and for most purposes time is measured by a fictitious sun or "mean sun" which moves in a uniform rate along the equator. This is called *mean solar time*. The difference between mean and apparent time is called the *equation of time*.

To convert apparent time into mean time, take from the Nautical Almanac the equation of time and add it or subtract it according to the direction given at the column. The equation of time is sometimes defined as a quantity to be added algebraically to apparent time to get mean time. Its sign is plus when mean time is later than apparent time, and minus when earlier.

Siderial Time is measured by the daily motion of the stars, or the daily motion of the vernal equinox.

Siderial Day is the interval between two successive upper transits of the vernal equinox over the same meridian.

Siderial Noon is the instant the circle through the vernal equinox coincides with the meridian.

In order to connect siderial time with mean time an element is calculated and tabulated in the Nautical Almanac, that is, the Siderial Time of Mean Noon, or what is the same, the Right Ascension of the Mean Sun. Hence the Siderial Time as found by the sun is,

Siderial Time = Right Ascension Sun + Hour Angle of Sun.

When the hour angle is 0 the Right Ascension is the Siderial Time.

Astronomical and Civil Time. In astronomical time the day begins at noon and is divided into 24 hours, numbered successively from 0 h. to 24 h. The civil day begins at midnight, or when the sun is at the lower transit. It is divided into two parts of 12 hours each, the part from midnight to noon being called A.M. and from noon to midnight P.M. The civil day begins 12 hours before the astronomical day of the same date.

Ast. Time August 20, 17 hours = Civ. Time Aug. 21, 5 hours A.M.

Ast. Time August 20, 7 hours = Civ. Time Aug. 20, 7 hours P.M.

The hour angle of the sun at any meridian is called the local (Solar) time. The hour angle at Greenwich at the same instant is the corresponding Greenwich time. The difference between these two times is equal to the longitude of the place in time, which may be changed to degrees, minutes and seconds by the table previously given. Thus the longitude (generally speaking) is found at sea by getting the sun's hour angle, by aid of a sextant, and at the same time noting the chronometer time, the difference between the two being the longitude of the place of observation in time.

The Nautical Almanac, a portion of which is inserted on pages 50 and 51, gives part of the data needed to work up a sight. The Almanac is arranged as represented here, with the right ascension, declination, etc., of the sun corresponding to Greenwich apparent noon on this left-hand page and those corresponding to Greenwich mean noon on the right. The table for mean noon is the one to use, as we get Greenwich mean time from the chronometer.

Longitude at Sea by the Sun. In order to solve this problem it is necessary to know the following: Greenwich mean time at the time of observation, the sun's true altitude, declination, and the latitude of the place of observation. It is customary at sea to take a time sight in the morning about nine o'clock, and to work it through, using for latitude the latitude by account (which is obtained by the aid of the log and traverse table, as previously explained), thus getting the apparent time at ship and also noting the time by the ship's clock (not by the chronometer); thus the ship time for the day is found. Should the sun be in the prime vertical at the time of taking its altitude, the latitude by account may be used then and there to work out the ship's longitude, for with the sun in the prime vertical an error in the latitude produces no error in the longitude; otherwise the longitude must not be reckoned until the latitude of the ship is found at noon. Having obtained the latitude by meridian altitude, the latitude at the time of the morning observation may be found and used in working up the longitude. It is a good plan to get the sun in the prime vertical if possible; however, the altitude should not be too small to be seriously affected by refraction.

Let us now carry through a complete case, with every step plainly indicated, which the student must follow carefully.

The usual method followed is given by the following rule: Add together the true altitude, the latitude, and the polar distance; divide this sum by 2 and subtract the altitude; find from table 44, Bowditch, the log sec. of the latitude; the log cosec. of the polar distance; the log cos. of $\frac{1}{2}$ the sum of the altitude, latitude, and polar distance, and the log sin. of $\frac{1}{2}$ the sum minus the altitude; add these from logs and divide the sum by 2, and the quotient is the log sin. of $\frac{1}{2}$ the hour angle. The steps are indicated in the following practical case:

Example: At sea, May 6, 1902, the ship's position being lat. 41° 25′ N, long. 7° 320′ W by account (dead reckoning) from position at noon on May 5, the following observations were made:

Sun's altitude, lower limb	29° 4′
Time by ship's clock	$7^h\ 55^m$
Chronometer	$0^h\ 7^m\ 51^s$
Log	15
Course W N W true	
Chronometer correction	$+\ 4^m\ 59^s$
Index error of Sextant	— 1′
Barometer	30.32 inches.
Thermometer	59°
Height of eye	17 ft.

Chronometer, May 6	$0^h\ 7^m\ 51^s$
Chronometer correction	$+\ 4^m\ 59^s$
	$0^h\ 12^m\ 50^s$ = Greenwich.

Mean time May 6 (astronoinical time).

Alt. (sun's) $\underline{\odot}$	29° 41′ 0″	Index error	— 1′ 0″
Correction (A)	9′ 16″	Dip, Bowditch, Table 14	— 4′ 2″
True alt. sun's center	29° 50′ 16″	Refraction, Bowditch, Table 20	— 1′ 42°
		Semidiam. Nautical Almanac	+ 15′ 52″
		Parallax, Bowditch, Table 16	+ 8″
		Correction (A)	+ 9′ 16″
Declination May 6, Nautical Almanac.	16° 20′ 48.5 N	Hourly diff.	+ 42.57″
	8.5	corr. for 12m.	+ 8.5″
Corrected Decl.	16° 20′ 57″ 0		
Polar Distance	73° 39′ 3″		
Equation of Time Nautical Almanac	$3^m\ 26.23^s$ added to mean time.	[The correction here for 12m. is too small to take account of.]	

At noon, May 6, the latitude by meridian altitude was found to be 41° 40′ N, the log read 33 and the course steered during the morning was W N W, true. The distance run from the time of morning sight at 7:55 to noon was given by the log 33 — 15 = 18 miles. Table I, Bowditch, for W N W course, distance 18, gives diff. lat. 6.9; departure 16.6; diff. long. 22′.

∴ Lat. by account at 7:55 A.M. is 41° 4′ + 6.9′ = 41° 33.1′ or 41° 33′.

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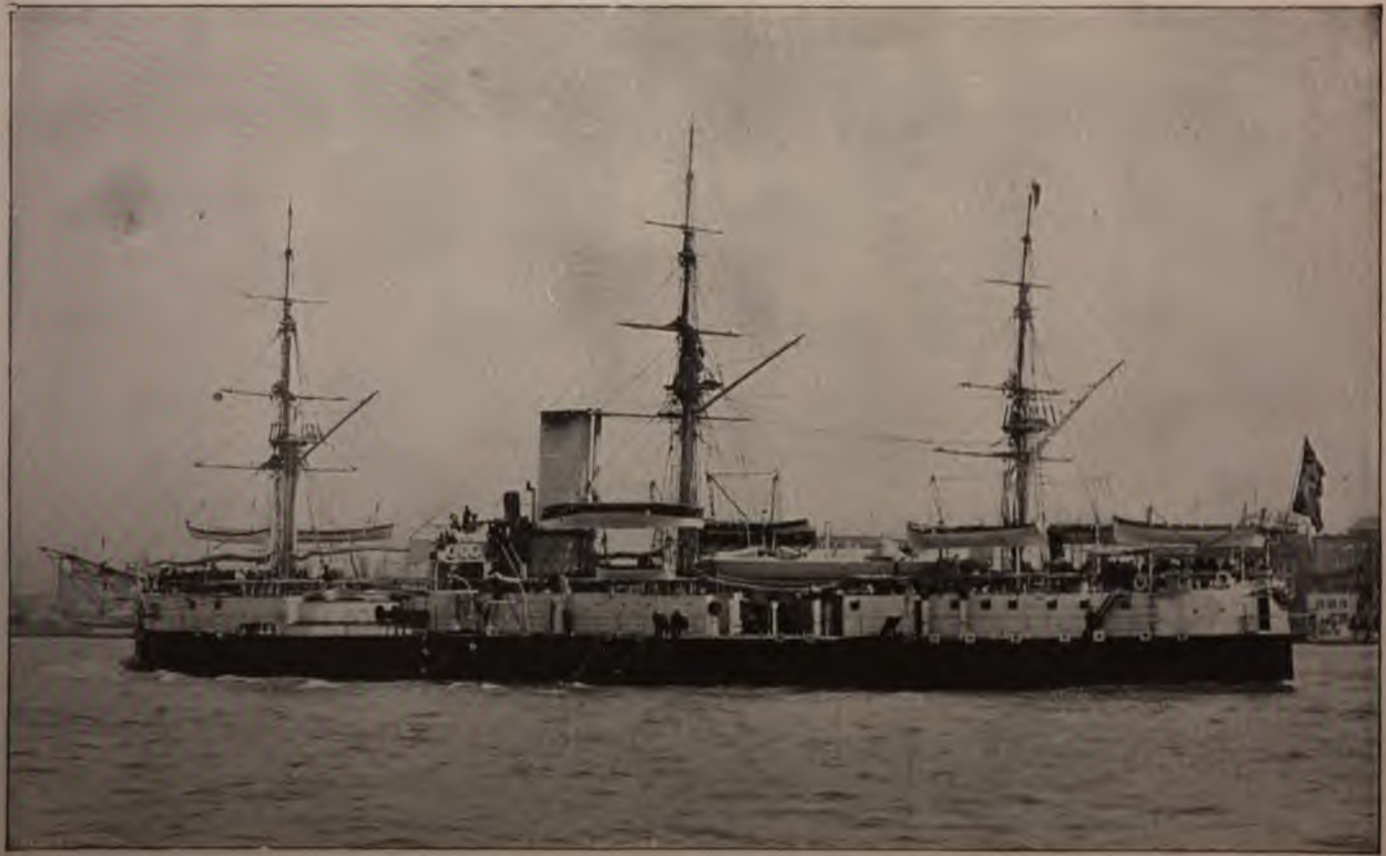

THE "AQUIDABRAN" OF BRAZIL

This latitude is to be used in working out the morning sight.

Alt.	29° 50′ 16″		
Lat.	41° 33′ 0″	log sec.	0.12588
Polar Dist.	73° 39′ 3″	log cosec.	0.01793
Sum.	145° 2′ 19″		
½ Sum.	72° 31′ 9″	log cos.	9.47767
	29° 50′ 16″		
½ Sum. — Alt. =	42° 40′ 53″	lon. sin.	9.83120
			2)19.45268
$7^h\ 42^m\ 35^s$ A.M., log ½ sin t			9.72634

The ship's clock gave the time as 7.55 when the time by the sun was found to be 7.42, which makes the ship's clock 13 minutes fast.

This is the apparent time at ship and is found in Bowditch, Table 44, corresponding log sin. 9.72634. As the chronometer (corrected) gives mean time it is necessary to find the mean time at ship at the time of observation, as follows :

$7^h\ 42^m\ 35^s$ apparent time
— 3 26 Eq. of time
$7^h\ 39^m\ \ 9^s$ mean time at ship.
12
$19^h\ 39^m\ \ 9^s$ astronomical mean time at ship, May 5.

Greenwich mean time (astronomical) $0^h\ 12^m\ 50^h$, May 6.
$0^h\ 12^m\ 50^s$ May 6 = $24^h\ 12^m\ 50^s$ May 5.
$19^h\ 39^m\ \ 9^s$ May 5.
Subtract $4^h\ 33^m\ 41^s$ = long. in time.
68° 25′ 15″ W long. at 7.55.
22 diff. of long.
68° 47′ 15″ W longitude reduced to noon, May 6.

In practice it is customary to work up the time sight, using the latitude by account, thus finding at once the approximate correction for the ship's time. It must, however, be worked through again to get the longitude as indicated by the problem. It requires practice to enable one to handle the longitude problem expeditiously.

A short method of checking the longitude sight is to get an altitude of the sun before its meridian passage, say at eight or ten minutes before; note the chronometer time at the instant of observing the altitude. Watch the sun, and when it again comes to the same altitude note the chronometer time ; the mean of the chronometer times gives the Greenwich mean time of apparent noon; this Greenwich mean time must be corrected for the equation of time, and when thus corrected it gives the longitude in time, which is of course changed into degrees, minutes and seconds.

Page from the Nautical Almanac giving right ascension, declination, etc., of the sun corresponding to Greenwich apparent noon.

AT GREENWICH APPARENT NOON.

Day of the Week.	Day of the Month.	THE SUN'S					Sidereal Time of Semi-diameter Passing Meridian.	Equation of Time to be Subtracted from Apparent Time.	Diff. for 1 Hour.
		Apparent Right Ascension.	Diff. for 1 Hour.	Apparent Declination.	Diff. for 1 Hour.	Semi-diameter.			
		h m s	s	° ′ ″	″	′ ″	s	m s	s
Thur.	1	2 31 00.58	+ 9.528	N.14 52 24.0	+ 45.78	15 53.28	65.92	2 53.92	0.328
Frid.	2	2 34 49.53	9.551	15 10 35.4	45.16	16 53.04	66.00	3 01.51	0.305
Sat.	3	2 38 39.03	9.574	15 28 31.8	44.54	15 52.81	66.09	3 08.55	0.282
SUN.	4	2 42 29.10	+ 9.598	15 46 13.1	+ 43.90	15 52 58	66.17	3 15.02	0.258
Mon.	5	2 46 19.74	9.622	16 03 38.8	43.24	15 52.35	66.25	3 20.91	0.234
Tues.	6	2 50 10.95	9.646	16 20 48.5	42.57	15 52.13	66.33	3 26.23	0.210

If the apparent time is ahead of mean time, add the equation of time to the mean chronometer time found; if behind mean time, subtract it. The chronometer's correction must also be applied, as in the longitude problem. This method should not be used in high latitudes.

SUMNER'S METHOD.

The following paragraph is taken from Bowditch, Art. 314: "By the various methods which have heretofore been described, in which single observations are alone concerned, the latitude has been found which places the ship upon a certain east and west line; by others the longitude has been found which places the ship upon a certain north and south line; but in neither case can the ship be located upon any particular point of the line. For instance, by the A.M. observation when the sun is near the prime vertical, the hour angle is determined with a certain degree of accuracy depending on the latitude by account, from which the

Page from the Nautical Almanac giving right ascension, declination, etc., of the sun corresponding to Greenwich mean noon.

AT GREENWICH MEAN NOON.

Day of the Week.	Day of the Month.	THE SUN'S				Equation of Time to be Added to Mean Time.	Diff. for 1 Hour.	Sidereal Time or Right Ascension of Mean Sun.
		Apparent Right Ascension.	Diff. for 1 Hour.	Apparent Declination.	Diff. for 1 hour.			
		h m s	s	° ′ ″	″	m s	s	h m s
Thur.	1	2 31 01.04	+ 9.529	N.14 52 26.2	+ 45.78	2 53.94	+ 0.328	2 33 54 98
Frid.	2	2 34 50.01	9.552	15 10 37.7	45.16	3 01.53	0.305	2 37 51.54
Sat.	3	2 38 39.53	9.575	15 28 34.2	44.54	3 08.56	0.282	2 41 48.09
SUN.	4	2 42 29.62	+ 9.599	15 46 15.5	+ 43.90	3 15.03	+ 0.258	2 45 44.65
Mon.	5	2 46 20.28	9.623	16 03 41.2	43.24	3 20.92	0.234	2 49 41.20
Tues.	6	2 50 11.51	9.647	16 20 50.9	42.57	3 26.24	0.210	2 53 37.75

longitude is ascertained; hence the position of the ship is approximately known upon a certain meridian. Again, by the meridian observation, when possible to obtain it, the position of the ship is known upon a certain parallel of latitude; and by a combination of the two observations the ship's position may be located upon the chart; but there has been involved a lapse of time, which under some circumstances may be vital for the safety of the ship.

"But by the Sumner method the ship is at once located upon a line, generally oblique to both parallels and meridians; and in approaching a dangerous coast the importance of this line is obvious, since it exhibits on the chart the bearing of the land." There are two distinct cases for this method; namely, by the altitudes of two objects taken at the same time; for example, two stars as near 90° apart as possible; and by altitudes of the same object, observed at different times; this is perhaps the common case, the sun being the object observed. The second case only will be given.

Stated briefly, Sumner's method consists of working up a time sight of the sun, using two assumed latitudes, one larger and the other smaller than the latitude by account. This is worked up in the same manner as in working the longitude problem, and as we have used two different latitudes we get two different positions for the ship; plot these two points on the chart and connect them by a straight line, the ship is somewhere on that line. After a lapse of about 1½ hours get another altitude of the sun, note the course steered and the distance run in the interval between sights. Work this new sight up, using the same two latitudes as before, plot the points found, thus obtaining a new line of position for the ship. Now move the first line of position parallel to itself a distance equal to the run in the lapse of time, between the two sights, on the course made good. The intersection between the second line of position and the first line moved as directed is the position of the ship at the time of second observation.

Bowditch, Art. 318: "At sea, June 27, 1879, A.M., observed the following altitudes of the sun to determine the ship's place by the intersection of the lines of position; the ship having run in the interval 25 miles on a course E true.

Ship's place by account first observation Lat. 49° 40′ N. Long., 5° 53′ 30″ W.

Ship's place by account second observation Lat. 49° 40′ N. Long., 5° 15′ W.
Chro. time, 8h. 24m. 14s. Equ. of time (1st) + 2m. 40s.
Chro. time, 10h. 51m. 40s. Equ. of time (2d) + 2m. 41.3s.
⊙'s declination, 23° 20′ 55″ N.
⊙'s true alt. (1st) 36° 24′ 20″. ⊙'s true alt. (2d) 58° 9′ 20″
Assumed latitudes, 49° 50′ and 49° 30′.

Alt.	36°	24′	20″			
Lat.	49	50	0	log sec	0.19043	
P.D.	66	39	5	log cosec	0.03711	
2)	152	53	25			
½ Sum (S)	76	26	42	log cos	9.36991	
	36	24	20			
½ S–Alt.	40°	2′	22″	log sin	9.80842	
					2)19.40587	
Local app. time,	7h.	57m.	34s.	log sin ½ t	9.70293	(Table 44)
Equ. of time	+	2	40			
Local mean time,	8h.	0m.	14s.			
G'nw'h " "	8	24	14			
Long.	0h.	24m.	0s.			
Long.	6°	0′	0″ W. (A)			

Alt.	36°	24′	20″		
Lat.	49	30	0	log sec	0.18746
P. O.	66	39	5	log cosec	0.03711
Sum	152	33	25		
½ Sum	76	16	42	log cos	9.37512
	36	24	20		
½ S-Alt	39	52	22	log sin	9.80692
					2)19.40661
Local app. time,	7h.	57m.	20.7s.	log sin ½ t	9.70330
Eq. time	·	2	40.0		
Local mean time	8	0	0.7		
G'nw'h " "	8	24	14.0		
Long.	0h.	24m.	13.3s.		
Long.	6°	3′	20″ W. (A_2)		

We can now plot these two positions, namely:
Lat. 49° 50 N, Long. 6° 0′ 0″ W, and Lat. 49° 30′ N, Long. 6° 3′ 20″ W, as shown by Fig. 21 at A_1 and A_2.

Alt.	58°	9′	20″		
Lat.	49	50	0	log sec	0.19043
P. D.	66	39	5	log cosec	0.03711
Sum	174	38	25		
½ sum	87	19	12	log cos	8.66985
½ S–Alt.	29	9	52	log sin	9.68781
				2)	18.58520
Local app. time	10h.	29m.	30.2s.	log sin ½ t	9.29260
Eq. of time		2	41.3		
Local mean time	10h.	32m.	11.5s		
G'nw'h " "	10	51	40		
Long.		19	28.5		
Long.	4°	52′	7″	W (B)	

Alt.	58°	9′	20″		
Lat.	49	30	0	log sec	0.18746
P. D.	66	39	5	log cosec	0.03711
Sum	174	18	25		
½ Sum	87	9	12	log cos	8.69603
½ S–Alt.	28	59	52	log sin	9.68554
				2)	18.60614
Local app. time	10h.	27m.	15.8s.	log sin ½ t	9.30307
Eq. time		+2	41.3		
Local mean time	10	29	57.1		
G'nw'h " "	10	51	40		
Long.	0h.	21m.	43s.		
Long.	5°	25′	45″	W (B_2)	

Plot these two positions, namely:

Lat. 49° 50′ 0″ N Long. 4° 52′ 7″ W
Lat. 49° 30′ 0″ N Long. 5° 25′ 45″ W

as shown by fig. 21 B, B_2. Move A, A_2 due east (the true course made good) parallel to itself 25 miles and draw it as shown by the dotted line A, A_2. Point of intersection O of dotted A, A_2 and B, B_2 is the position of the ship at time of second observation.

The ship position at O and the latitude and longitude of the spot is found as explained under the discussion of charts, etc.

TIDES.

The tide is the vertical and horizontal movement of the sea. Ordinarily the word tide is applied merely to the vertical movement, while the horizontal movements are called tidal currents. The rising of the water is called flood tide, the falling, ebb tide. The maximum height is called high water, distinguished by HW, the minimum is called low water (LW). The difference in elevation between high and low water is called the range of the tide.

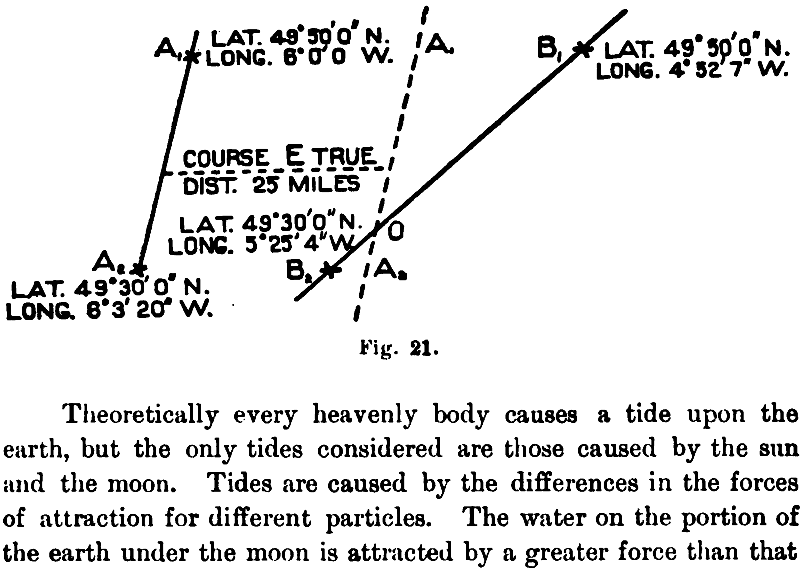

Fig. 21.

Theoretically every heavenly body causes a tide upon the earth, but the only tides considered are those caused by the sun and the moon. Tides are caused by the differences in the forces of attraction for different particles. The water on the portion of the earth under the moon is attracted by a greater force than that which attracts the earth as a whole. This force of attraction tends to elevate the surface at this portion of the earth. At the point opposite the moon, the water is attracted by a force which is less than the average, so that there is a tendency at this point also to elevate the surface. At points halfway between, the force tends to depress the surface. If the earth were set rotating, any place would pass through two high and two low tides during one revolution, or one day.

If the earth, moon and sun were at rest this would explain what would occur, but the motions of these bodies, the varying depth of the ocean and the interference of land, make the actual result quite complicated.

The tides at any particular point depend chiefly upon local conditions, and cannot be exactly predicted, except from a long series of observations made at that point.

Effect of Changes in the Moon's Declination. When the moon is on the equator the two successive high tides would be of nearly the same height. When, however, the moon has a large north or south declination the two tides differ, as is shown in the figure.

The moon attracts the earth with a greater force than it does the water on the opposite side, so that this part of the sea remains as it was. At a point B, under the moon, it is high water and the depth is greater than usual. Twelve hours later the same place will be at B, where it will be again high water, but not as high as usual. This is called the diurnal inequality. At points on the equator there is no inequality.

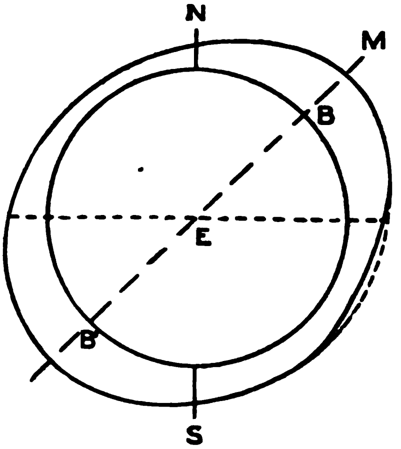

Fig. 22.

Effect of Moon's Distance. When the moon is nearest the earth (at perigee), the attraction is greater than the average and the tides are increased. When the moon is farthest from the earth (at apogee), they are decreased. Similarly, when the earth is nearest the sun (at perihelion), the attraction is increased. At aphelion it is decreased.

The force causing the solar tide is only a little more than one-third that which causes the lunar tide. At new and full moon, the sun, moon and earth are nearly in the same line, so that the solar and lunar tides combine and make the resulting tides higher than usual. These are called *spring tides.* When the moon is 90° from the sun (at quadrature) the two tides tend to neutralize and the result is comparatively low tides. These are called *neap tides.*

On the days of new and full moon high water follows the moon's meridian passage by a certain interval of time depending upon the place. This interval is called the "establishment" of that port. At quadrature the high tides, although lower than usual, will follow by this same amount. Between these two positions the solar and lunar tides combine, so that the crest of the resulting wave is between the two. The result is that for a few days after new or full moon the crest of the wave is west of the lunar tide and high tide occurs earlier than the average. This is called the "priming" of the tide. A few days before new or full moon the crest is behind the lunar tide. This is called "lagging."

Effect of Wind and Change of Air Pressure. When the wind blows steadily into a bay or harbor the water is piled up and the height of tide increased. The time of high water is delayed; for the water continues to flow in after the predicted time has passed, so that the maximum does not occur until the effect of the wind and the ebb of the tide are balanced. When the pressure of the air is greater than usual the surface of the water is depressed below the normal. When the pressure is less, the height of the surface is greater. The amount of this change is usually small.

Compass Deviation by Azimuth of the Sun. The handiest method to use at sea in a sailing vessel, when an azimuth circle is not at hand and the apparent time at ship is fairly accurately known, and also the latitude, is to fix a shadow pin (not an iron one) erect over the center of the glass over the compass and get by its aid the compass bearing of the sun; then find from an azimuth table the true azimuth for the latitude, as explained in such tables. The compass bearing of the sun should be corrected to allow for the magnetic variation at the place, and the difference between the true azimuth and the corrected compass bearing is the deviation of the compass.

If an azimuth table is not at hand, the azimuth may be worked as indicated on pages 149–153 Bowditch, either by the method of time or altitude azimuths; the time azimuth is generally the best method if the apparent time and latitude are fairly well known. This matter is not explained at length here, as such constant reference to Bowditch's tables have to be made. The navigator at sea has these tables, and in the portion preceding the tables an explanation of both time and altitude azimuths is given.

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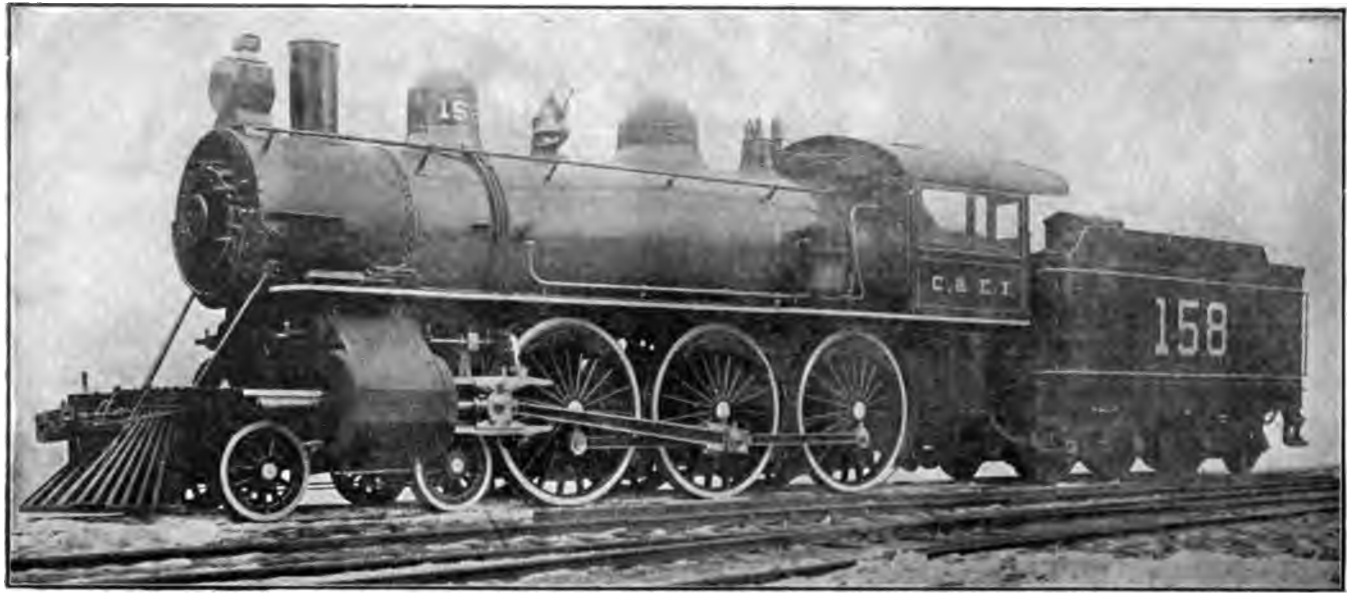


Representative American Locomotive, Built by the American Locomotive Company.

LOCOMOTIVE BOILERS AND ENGINES.

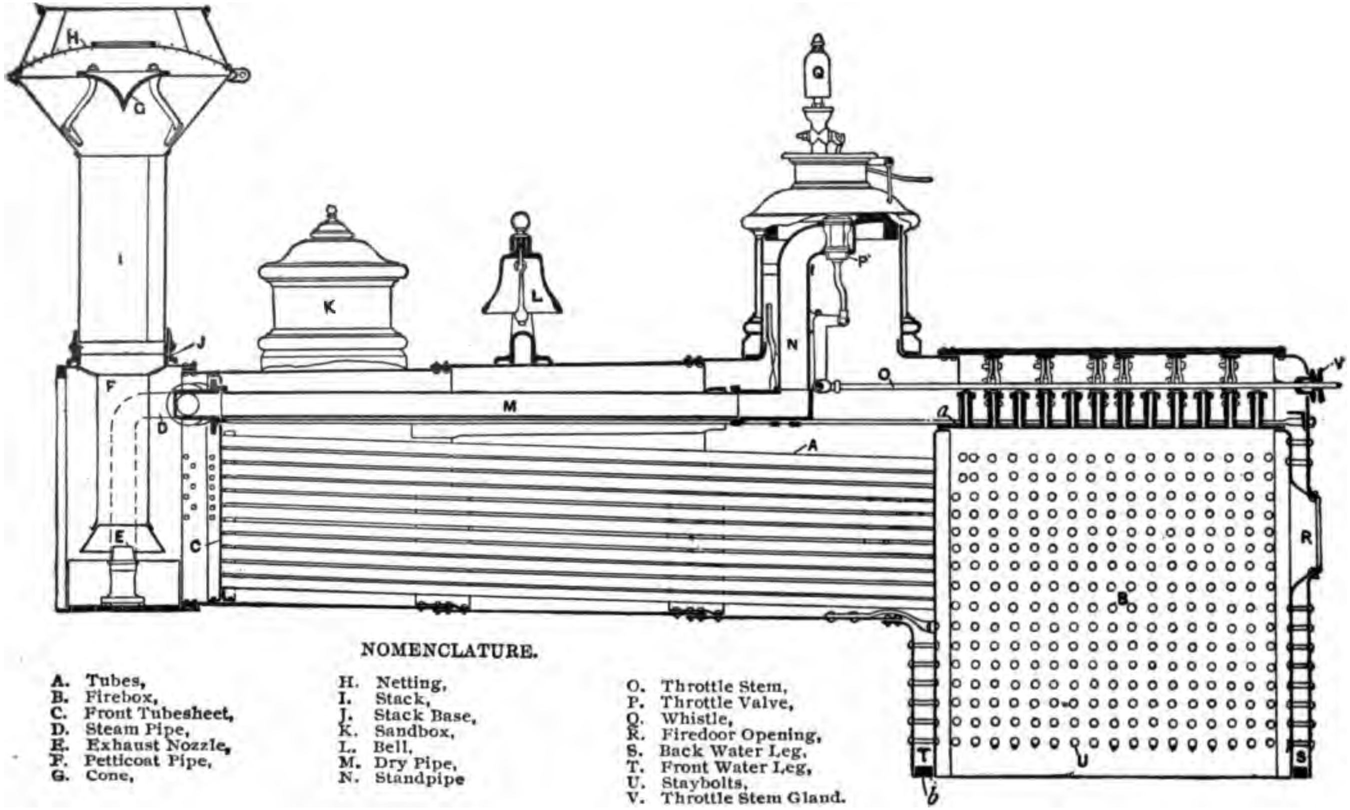
PART I.

The locomotive differs from the ordinary steam engine only in the fact that the engine and boiler are attached to the same frame, and are so arranged that the whole mechanism is self-propelled over the track upon which it rests. The power that a locomotive is capable of developing depends upon the size of the cylinders and boiler. Owing to transverse limitations imposed by structures on either side of the track, the size of the locomotive must be kept within certain limits. Up to the present time it is the boiler that sets the limit to the power that a locomotive is capable of exerting. Cylinders can easily be constructed that will use all of the steam that the boiler can generate. The tendency, therefore of modern locomotive construction has been towards an increase in the size of the boiler. The larger the boiler, the greater will be the amount of heating surface that it will contain and the more steam it will supply.

The boilers used upon locomotives are of a distinct type. They consist of a cylindrical barrel or shell, which is nearly filled with tubes. The back ends of these tubes open into the firebox, which is formed by two plates of metal spaced from 3 in. to 4 in. apart. Such a boiler is shown in Fig. 1. In this boiler A represents the nest of tubes and B the firebox. All locomotive boilers conform to this general description. There are, however, great variations in the shape and size of the firebox and the method of staying the flat surfaces.

There is one almost universal method of staying the flat surfaces of the firebox at the sides and front. This is by the use of staybolts. These staybolts are screwed through the two sheets of the firebox and are riveted over on the outside.

Fig. 2 shows a staybolt screwed into position. This is a common form but is not the best. A stronger and better form is shown in Fig. 3. In this, the staybolt is cut away between the sheets and only sufficient thread is cut at the ends to give it a hold in the metal. In Fig. 3, A represents the inside sheet or the one next the fire and B represents the outside sheet. A



NOMENCLATURE.

A. Tubes,
B. Firebox,
C. Front Tubesheet,
D. Steam Pipe,
E. Exhaust Nozzle,
F. Petticoat Pipe,
G. Cone,

H. Netting,
I. Stack,
J. Stack Base,
K. Sandbox,
L. Bell,
M. Dry Pipe,
N. Standpipe

O. Throttle Stem,
P. Throttle Valve,
Q. Whistle,
R. Firedoor Opening,
S. Back Water Leg,
T. Front Water Leg,
U. Staybolts,
V. Throttle Stem Gland.

Fig. 1.

small hole C is usually drilled into the end of the staybolts at C. This is known as a tell-tale hole and serves to allow an escape of water if the bolt becomes broken. The tell-tale hole is only drilled at the outer end as staybolts almost invariably break off close to the outer sheet. The crack or break thus formed, permits the escape of water indicating that a fracture has occurred.

Staybolts are broken because of the bending at the point *a* (Fig. 3) due to the inequality of the expansion of the sheets A and B. The sheet A being next to the fire is kept at a higher temperature, while the boiler is at work, than the sheet B, which lies next to the air.

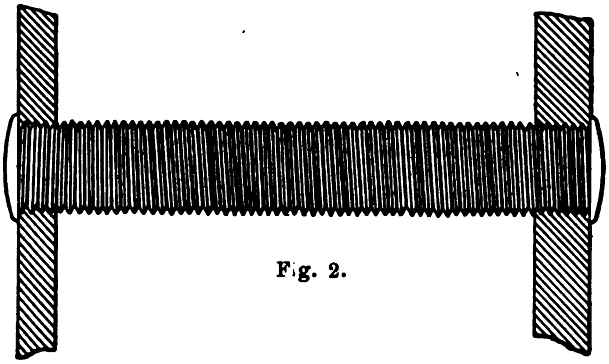


Fig. 2.

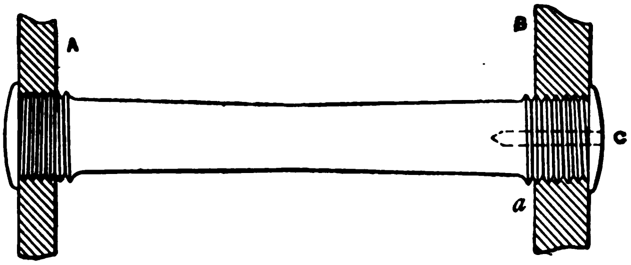


Fig. 3.

In order to avoid these bending stresses, a number of different forms of flexible staybolts have been designed. One form of these is shown in Fig. 4. The staybolt proper A has a ball formed on one end and has a thread cut on the other. A plug sets over the ball and forms a socket in which the latter can turn. As the

[illegible]

[illegible] Fig. 5. [illegible] and are fastened to [illegible] A further support is also [illegible] are fastened to the [illegible]

Radial Stay Boiler. The other method of supporting the crownsheet is that of the radial stay. A boiler so constructed is shown in Fig. 6. The staybolt construction that is used in the water legs at the sides of the fire-box is followed across the crownsheet. The staybolts are screwed into both sheets.

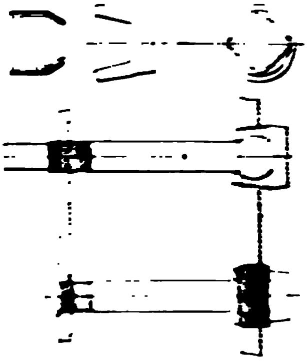
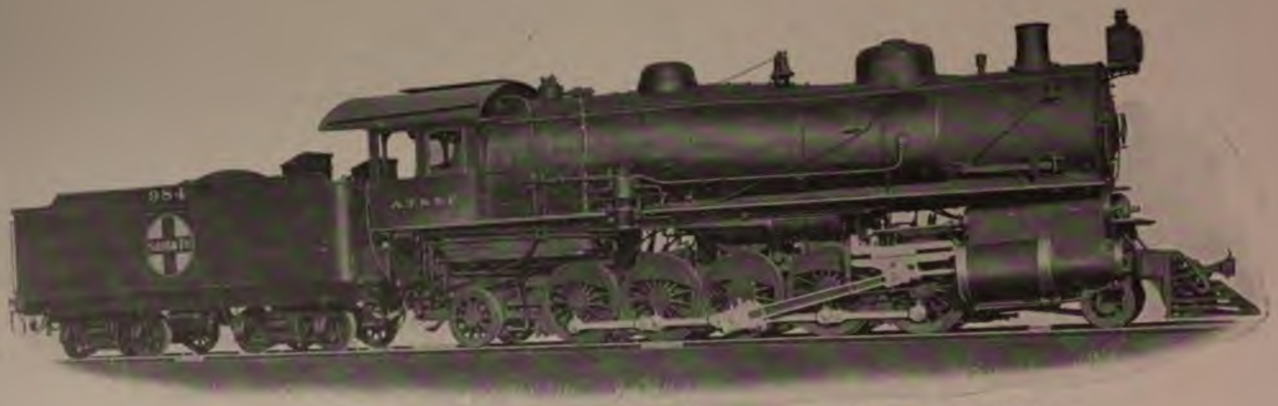


Fig. 4.

Owing to the fact that when the fire is first built and steam is being generated the inner sheets of the fire-box expand more rapidly than the outer, a flexible form of staybolt has been designed. This is shown in Fig. 7. There is a bolt a headed with a taper seat fitting into the crownsheet. Next the crownsheet there is a spacer b, against the top of which there is a washer c held firmly by the nut d. A bushing e is screwed into the outer sheet. This bushing has a seat for the washer. Over the bushing there is screwed the cap f. Then as the crownsheet rises under the influence of expansion the washer is lifted from its seat on the bushing. It returns to it again when the steam pressure tends to force the crownsheet down.

Another form of flexible staybolt is shown in Fig. 8. The flexibility consists in so lengthening the bolt by means of a cap, that the bending angle is lessened with a corresponding decrease in the strain on the metal.



COMPOUND SANTA FE TYPE LOCOMOTIVE, FOR HEAVY FREIGHT SERVICE,
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Sometimes sling stays are used instead of flexible stays. his construction is shown in Fig. 9.

Types. In the outer form of the boiler there are two types·

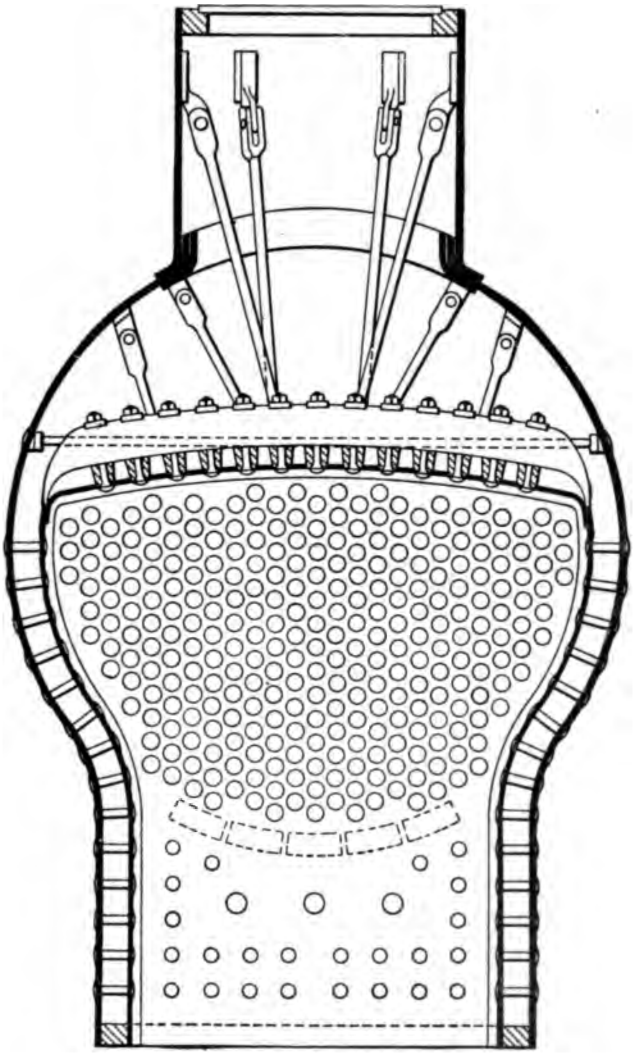

Fig. 5.

e straight-top as illustrated in Fig. 1, and the wagon-top as own in Fig. 10. The wagon-top boiler has a rise from the shell the outer sheet of the firebox. The object of the wagon-top construction is to give additional steam space within the boiler. It was extensively used a few years ago. Since the size of boilers has been increased and they have been raised high above the rails, there has not been headroom enough in tunnels and bridges to use this type of construction. The straight-top is, therefore, now extensively used.

Belpaire Boiler. A form of boiler known as the Belpaire is now in common use. The peculiarity of this boiler lies in the fact that the inner and outer sheets at the crown are horizontal, and the sides enclosing the space above the crownsheet are vertical and parallel. This construction is shown in Fig. 11.

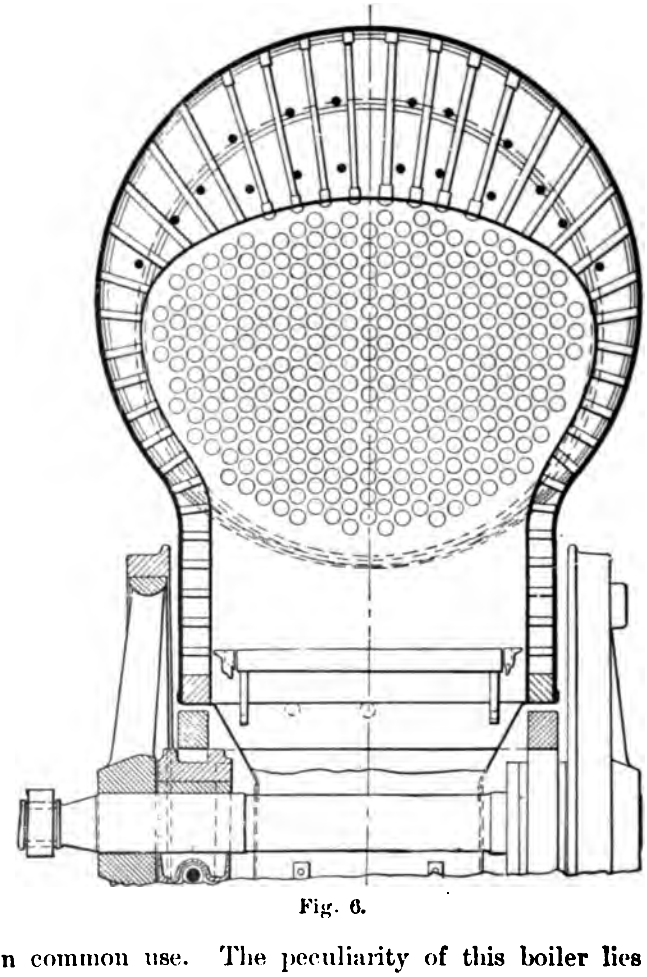

Fig. 6.

The advantage of this method is that the staybolts holding the crownsheets and sides can be placed at right angles to the sheets into which they are screwed. There is, therefore, no cramping or bending of the bolts when the working stresses are applied.

Wootten Firebox. Where fine anthracite coal is burned a much larger firebox is required than in the case of bituminous coal. The firebox need not, however, be as deep. The Wootten firebox is very wide and very shallow. The boiler is raised so that the grates are above the tops of the driving wheels. The firebox can, therefore, be made as wide as the clearance spaces of the roadway will permit. Such a firebox is shown in cross section in Fig. 12. As originally designed the Wootten firebox had a combustion chamber between the throat sheet at the front of the grates and the tubes as in Fig. 13. The combustion chamber is represented at *a*. The grates occupy the space indicated at *b*. The combustion chamber has been found to be unnecessary and has not been applied to any great extent in recent years.

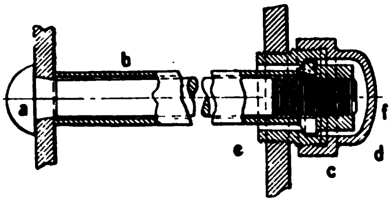

Fig. 7.

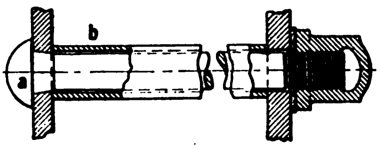

Fig. 8.

The Lentz Boiler. The Lentz boiler is shown in longitudinal section in Fig. 14. The object aimed at in this boiler is to avoid the use of stays. In order to accomplish this there are no flat surfaces, with the exception of the front and back tubesheets *b* and *a*, and these are stayed by the tubes themselves. The firebox is formed of a corrugated sheet. It is circular and requires no staying. The shell of the boiler is of course circular. The outer shell of the firebox is conical. Its smaller diameter is but slightly larger than the outside diameter of the furnace to which it is riveted at the back ring *c*. These boilers have been used to a considerable extent in Europe, and a few have been built in this country.

Materials. The materials used in the construction of locomotive boilers in this country are wrought iron and mild steel. Steel may be said to be universally used for the shell, heads and firebox sheets. Steel has also been used for tubes and staybolts but wrought iron is the material in common use. Wrought iron is also used for the mud ring (See *b* Fig. 1).

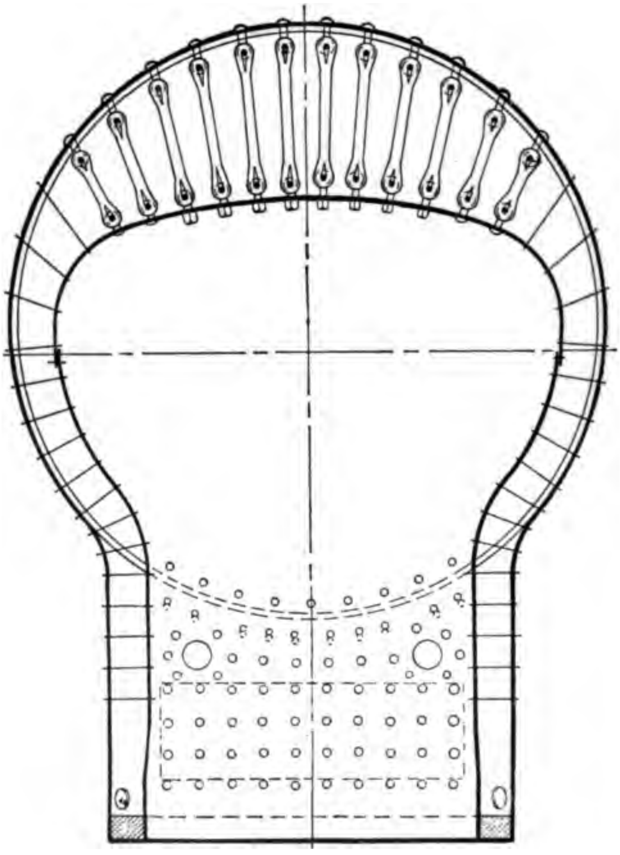

Fig. 9.

The American Railway Master Mechanics' Association have recommended that the steel used in locomotive boilers shall be homogeneous throughout. That, when it is broken, it shall show no laminations as much as ¼ inch in length. It must be possible to bend the metal double either hot or cold, without having it show any crack or flaw, after it has been heated to a cherry red and quenched in water having a temperature of 85 degrees Fahrenheit. The tensile strength must not be more than 65,000 lbs. per square inch of section or less than 55,000 lbs. In the testing machine a piece of the steel 8 inches long must stretch 25 per cent of its length, if intended for the shell, and 28 per cent of its length, if intended for the firebox, before breaking. There should be as little phosphorus, sulphur, manganese and silicon in the steel as possible. The carbon should be as near .18 of one per cent as it can be made. When these specifications are met the metal will be soft and ductile, with ample strength and not likely to break or crack under the stresses to which it

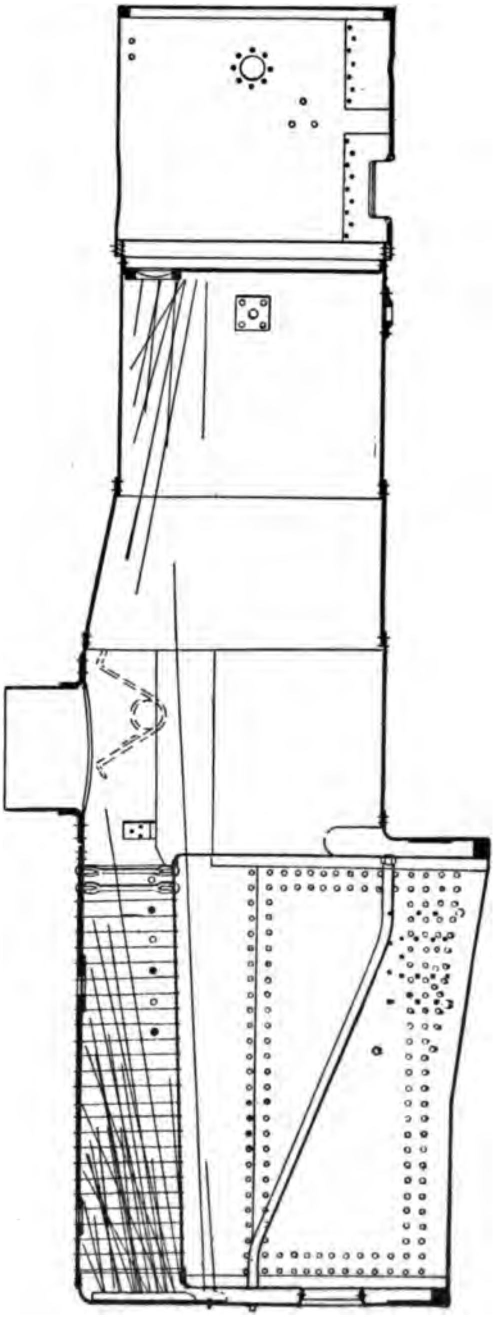

Fig. 10.

will be subjected while at work or in course of preparation.

The tubes are made of soft wrought iron free from impurities and easily welded.

The bar iron used for braces and other parts should have a tensile strength of from 50,000 lbs. to 60,000 lbs. per square inch of section. The strength desired is 55,000 lbs. with an elongation, before breaking, in an 8-inch test piece, of 25 per cent.

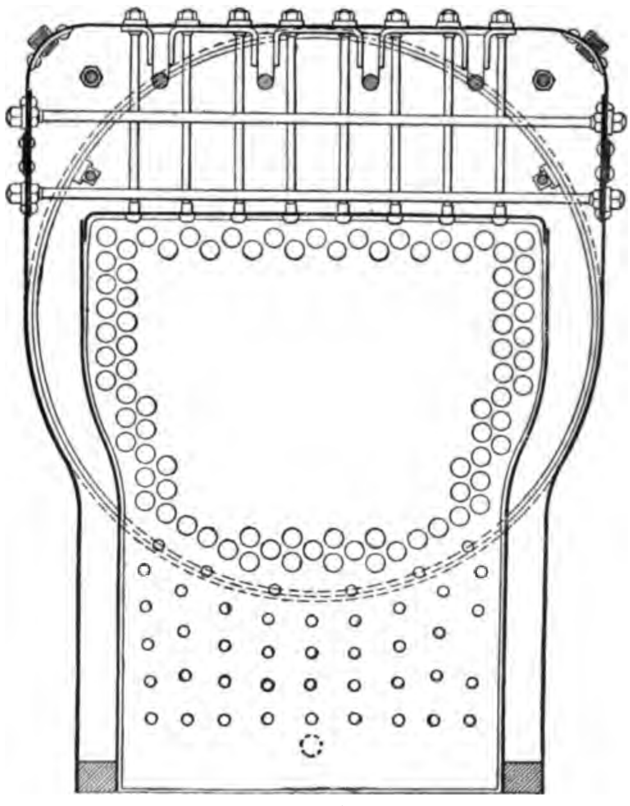

Fig. 11.

Staybolt iron need not be quite as strong as bar iron. The strength desired is 50,000 lbs. per square inch of section, but it must not be less than 48,000 lbs. As this metal is usually softer than the bar iron the elongation is greater and should be 30 per cent. If it falls below 28 per cent. the metal will be rejected by reliable builders.

All iron should be free from seams and mechanical defects and show a uniformly fibrous fracture.

The Fire Box. The locomotive firebox is limited in size by the other portions of the boiler, the machinery of the engine and the clearance spaces along the side of the road. For many years the firebox was placed between the frames. As these frames were at least $3\frac{1}{2}$ inches wide, and an allowance for clearance of $\frac{3}{8}$ inch on each side was made, to which $3\frac{1}{2}$ inches on each side was to be added for the water leg, the total width of the inside of the firebox was reduced to about 2 feet 10 inches as shown in Fig. 5.

In 1880 Mr. Theo. N. Ely designed what is known as the Pennsylvania Class K. locomotive. In this engine the firebox was placed on the top of the frames and was the full width of the same. This added about 7 inches to the width of the firebox. The arrangement is shown in Fig. 6.

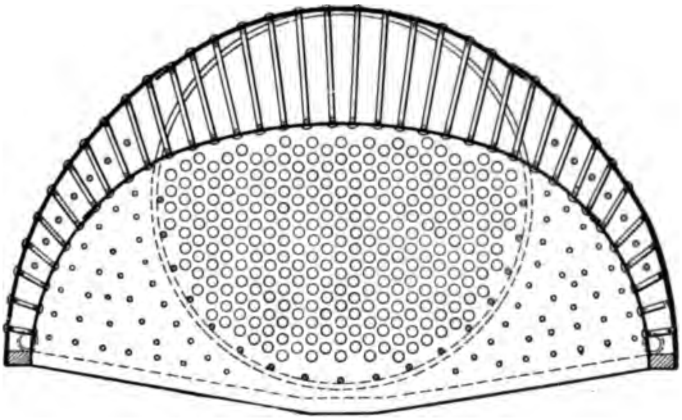

Fig. 12.

Placing the firebox over the top of the driving wheels added to the possible width. The width of this type of box is only limited by the space available for the total width of the engine. It may be made $8\frac{1}{2}$ feet or more wide over all, and about 8 inches less on the inside. Such a box is shown in section in Fig. 12.

When the firebox was placed between the axles the length of the firebox was limited by the distance between the driving wheel centres and was rarely made more than 6 feet 9 inches long from which the front and back water legs were deducted leaving about 6 feet for the length on the grates. Placing the firebox on top of

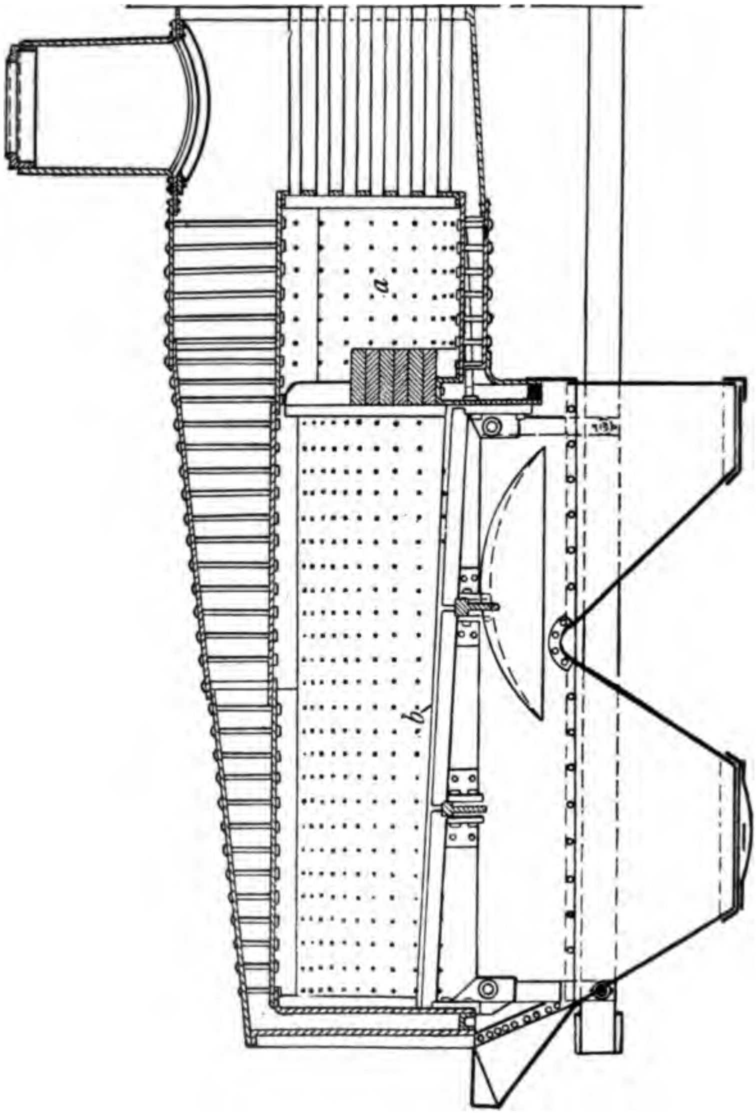

Fig. 13.

the frames has made any length possible, and the limit is imposed by the capability of the fireman to throw coal to the front end of

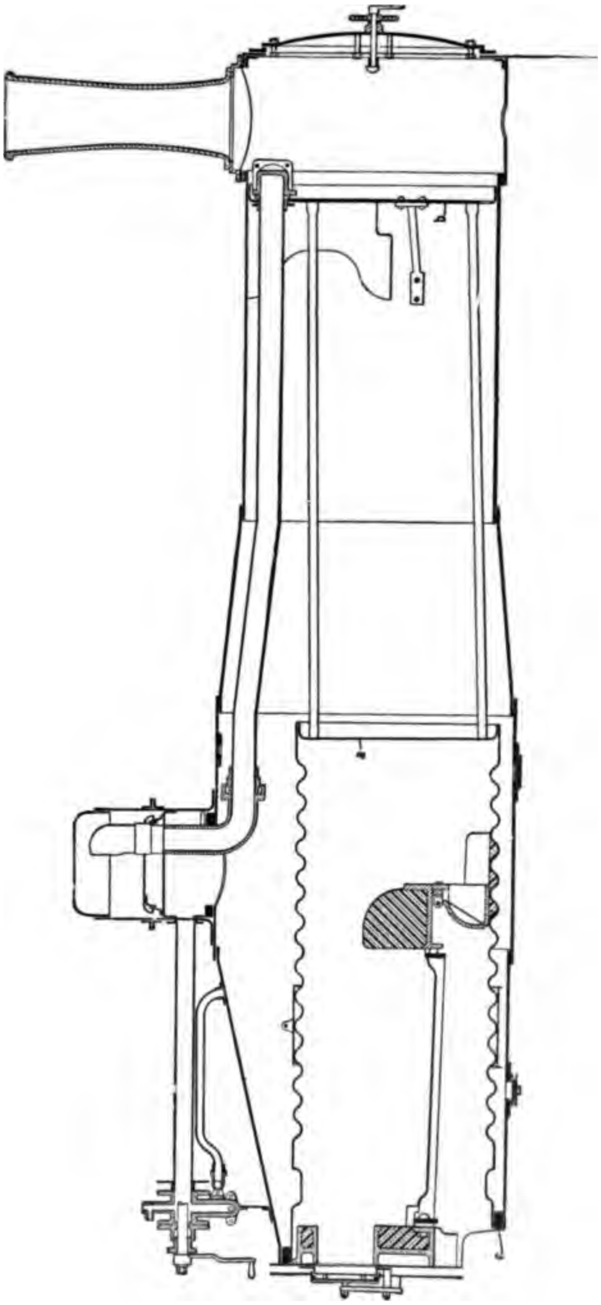

Fig. 14.

the box. These fireboxes are now made from 11 feet to 12 feet in length.

Shape. The general shape of the firebox is rectangular in plan. The vertical cross-section is approximately balloon shaped as shown in Figs. 5, 6, 9 and 11.

Combustion Chambers are but little used. An example of this type of firebox is shown in Fig. 13. Combustion chambers have not been found to add enough to the steaming qualities of an engine to pay for the extra expense involved in their first cost and maintenance.

Side Sheets. The side sheets of a firebox are usually made of sheets thinner than those of the shell of the boiler. They are in the form of flat surfaces that must be supported by staybolts as already described. The usual thickness of side sheets for boilers carrying a steam pressure of from 180 to 200 lbs. per square inch is $\frac{3}{8}$ inch. This sheet may be considered as a number of rectangular beams fastened at the ends and uniformily loaded. A description of the properties of beams is given in Mechanics. Experiments have shown, however, that the strength of flat stayed surfaces does not vary exactly with the square of the thickness. The formula given by the United States Bureau of Steam Engineering for the calculation of the stress on flat stayed surfaces is:

$$S = 1.5 \frac{E\,t^2}{(d - a)^2}$$

In which

S = maximum stress in lbs. per square inch to produce permanent set;

E = elastic limit of plate about 32,000 lbs. for steel and 29,000 lbs. for iron;

t = thickness of plate;

d = distance center to center of stays;

a = diameter of head of stay.

ILLUSTRATIVE EXAMPLES.

1. What pressure per square inch of surface will be required to give a permanent set to a steel firebox sheet? The thickness is $\frac{3}{8}$ inch, the staybolts are spaced 4 inches from center to center and have heads $1\frac{1}{2}$ inches in diameter.

Ans. 1080 pounds per sq. inch.

2. What pressure per square inch of surface will be required to give a permanent set to a steel firebox sheet having a thickness of $\frac{5}{16}$ inch with staybolts spaced $4\frac{1}{2}$ inches from center to center and having heads $1\frac{3}{8}$ inches in diameter?

Ans. 480 lbs.

The stress put upon each staybolt is obtained by squaring the distance between centers, subtracting the sectional area of the bolt and multiplying by the steam pressure.

The stress per square inch of section of staybolt is obtained by dividing the total stress by the sectional area of the staybolt.

ILLUSTRATIVE EXAMPLES.

1. (a) What stress will be put upon each 1 inch staybolt of a firebox carrying a pressure of 180 lbs per square inch and having staybolts spaced 4 inches between centers? (b) What will be the stress per square inch of section of staybolt if they are 1 inch in diameter.

Ans. *a* 2738.63 lbs.
b 3486.9 lbs.

2. (a) What will be the stress put upon each $\frac{7}{8}$ inch staybolt of a firebox carrying a pressure of 160 lbs. per square inch, with staybolts spaced $4\frac{1}{2}$ inches from center to center? (b) What will be the stress on each square inch of section of the staybolts if they are $\frac{7}{8}$ inch in diameter?

Ans. *a* 3143.79 lbs.
b 5228.3 lbs.

The working pressure allowed on flat surfaces by the United States Board of Supervising Inspectors of Steam Vessels is determined by the following formula, which is applicable to firebox plates having a thickness of $\frac{7}{16}$ inch more or less.

$$P = \frac{T^2C}{D^2}$$

in which

P = the working pressure.
C = constant = 112 for $\frac{7}{16}$ inch plates and under.
C = constant = 120 for plates more than $\frac{7}{16}$ inch thick.
D = distance center to center of stays.
T = thickness of plate in sixteenths of an inch.

The rules also provide that the stress put upon a staybolt shall not exceed 6,000 pounds per square inch of section.

EXAMPLES FOR PRACTICE.

1. What will be the allowable working pressure on a firebox having plates $\frac{3}{8}$ inch thick with staybolts $4\frac{1}{2}$ inches from center to center? Ans. 199.1 lbs. per sq. in.

2. What diameter of staybolts are to be used in Example 1?

Note that the effective diameter is at the bottom of the thread. The average thread may be taken as 12 per inch. The diameter should be in even eighths of an inch.

Ans. $1\frac{1}{8}$ inches diam.

3. What will be the allowable working pressure on a firebox having plates $\frac{5}{16}$ inch thick, with staybolts spaced $4\frac{1}{2}$ inches from center to center? Ans. *a* 138 lbs. per sq. in.

Tubesheets are usually thicker than the side sheets. The reason is that there may be a greater width of bearing for the tubes. The tubesheet is, therefore, made about $\frac{1}{4}$ inch thicker than the side sheets. Thus where the side sheet has a thickness of $\frac{3}{8}$ inch, the tubesheet will be $\frac{5}{8}$ inch thick. Below the curve of the shell of the boiler the tube sheet is stayed in exactly the same manner as the side sheets. The portion facing the inside of the shell is stayed by the tubes. These are expanded and headed in position as described in the paper devoted to "Construction of Boilers."

Points of Maximum Breakage of Staybolts. The cause of the breakage of staybolts, due to the variations in the expansion of the two sheets of the water leg, has already been explained. This breakage is the greatest at points where the greatest amount of motion takes place. As the two sheets are rigidly fastened to the mud ring, it is evident that the variations of expansion must start from that point. Hence the greatest vertical variation will be found at the top of the firebox. In like manner the back heads are securely fastened by staybolts, so that the horizontal variations must start at the back end. Consequently the greatest horizontal variation will be found at the front end of the firebox. The resultant of these two expansions will, therefore, be greatest at the upper portion of the front end. It is there that the greatest number of staybolt breakages occur. In the application of the flexible staybolts, already described, they are put in only in this place where breakage is most likely to occur, while the ordinary form of staybolt as shown in Fig. 2, is used for the remainder of the firebox.

The length of the firebox has a noticeable effect on staybolt breakage. The longer the firebox, the greater the variation in the expansion and the greater the liability to staybolt breakage. No absolutely reliable experiments have as yet been made to determine just what this variation is under the varying conditions of construction and pressure.

Brick Arches. A brick arch is an arrangement placed in the firebox to effect a better combustion and secure a more even distribution of the hot gases in their passage through the tubes.

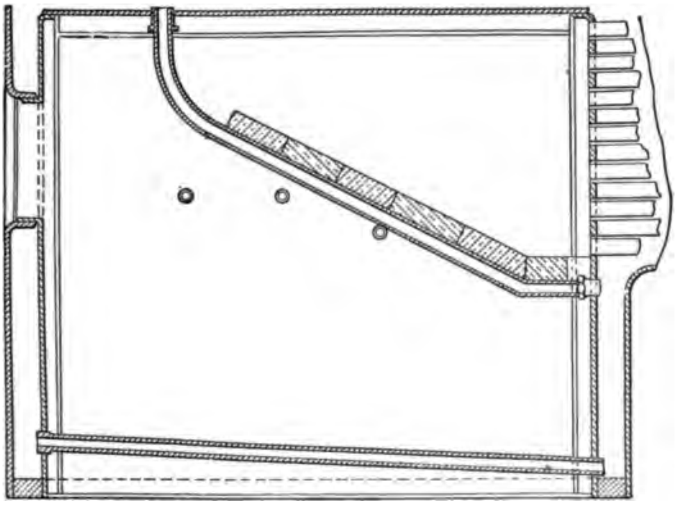

Fig. 15.

Fig. 15 represents a longitudinal section of a firebox fitted with a brick arch. Its method of action is very simple. It acts, at the same time, as a mixer of the products of combustion with the air that is admitted above the fire and as a reflector of the radiant heat of the fire and the escaping gases. It is also maintained at a very high temperature and, in that condition, it heats the air and gases as they come in contact with it and turns them back to the narrow opening above it. Through this threefold method of action, it maintains a temperature that is high enough to burn with the smallest possible quantity of air all of the carbonic oxide and the hydrocarbons that arise from the coal. It thus effects a very considerable saving in the cost of running; does away, to a great extent, with the production of smoke with comparatively heavy beds of fire, and develops a high calorific power in comparatively small fireboxes. This is a valuable property, as it enables the boiler to utilize the calorific value of the coal to the utmost.

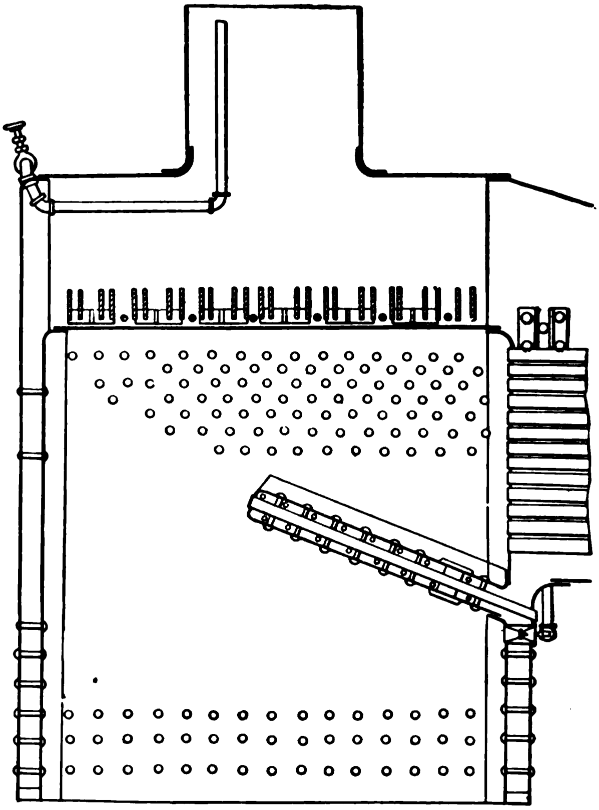

Fig. 16.

The bricks are usually about four inches thick and are ordinarily supported either by water tubes extending from the tubesheet to the crown sheet, as shown in Fig. 15, or by brackets in the form of angle irons riveted to the side sheets.

The disadvantage accruing from the use of the brick arch is hat it is somewhat expensive to maintain owing to the rapid leterioration and burning out of the brick.

Water Tables were intended as a substitute for the brick rch. They have been made and applied in various forms. ne of the earlier forms is shown in Fig. 16. The trouble vith this table was the deficiency of circulation. Steam vas likely to collect at the highest point and permit the metal o be burned. This was modified into the form shown in Fig. 17, and is known as the Buchanan firebox. In this the ipper and lower portions are connected and the products of comustion pass from the firebox through a hole in the table to the hamber. Tubes are also expanded in the sheets opposite the oot of the table for the cleaning of the combustion chamber. This table gives no trouble with burning out and the violent circuation keeps it free from scale and sediment.

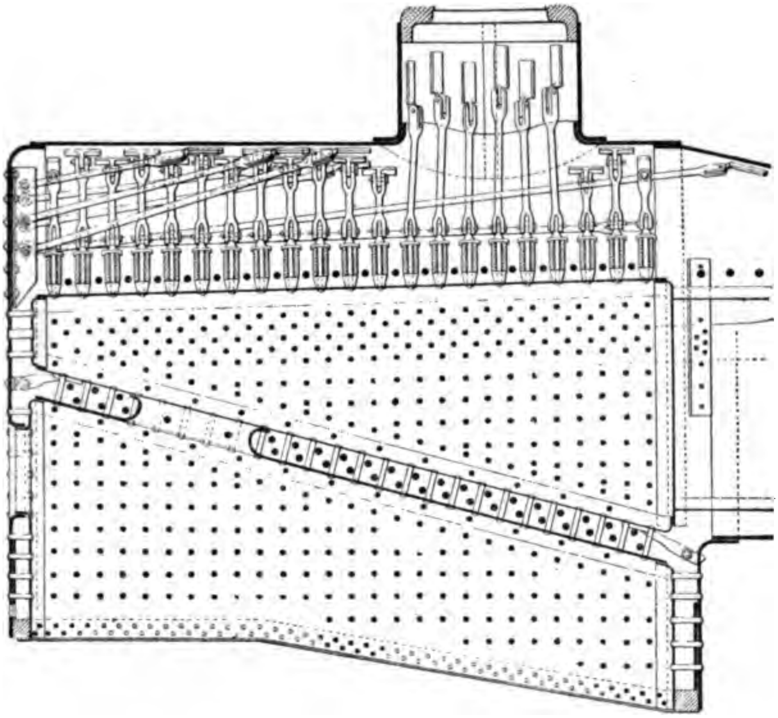

Fig. 17.

The disadvantage of this type of firebox is that it places a large cooling surface in the firebox at a point where it is desirable that the heat should be the most intense, and, owing to its rigidity it is very difficult to keep tight. It must be remembered that the difference between the temperature of the firebox sheets and the flames may be 1,400 to 1,600 degrees Fahr. This surface, therefore, acts as a cooling one on the fire. This leads to the production of smoke and cuts down the completeness of combustion.

Grates. The grates, upon which the fuel is burned, are placed at the bottom of the firebox. The material of which they are made is cast iron for the ordinary type. For water grates, wrought iron tubing is used.

The form of the grate and the dimensions of the air spaces between the bars vary with the fuel used. In wood-burning locomotives the grates are stationary and are supported by brackets bolted to the mud ring. One form of grate for wood-burning locomotives is shown in Fig. 18. The air spaces *a* and the bars *b* are of about the same width and vary from ⅜ inch to ½ inch. The sloping ends *cc* act like a wedge, when the grate expands, and push beneath the ashes that may have accumulated at the ends.

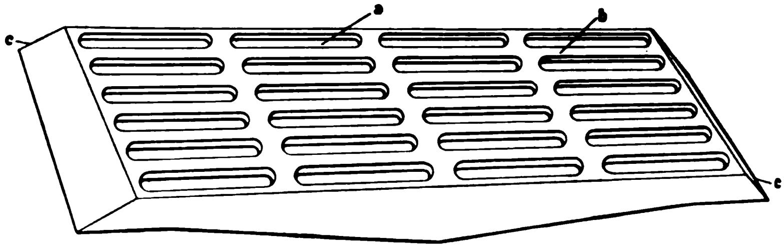

Fig. 18

When burning coal movable grates are invariably used. A great variety of designs have been tried. The most common form of grate for bituminous coal is that shown in Fig. 19. These grates consist of a central bar carrying the fingers which interlock with each other, forming the air spaces. The grates can be moved by a bar beneath connecting the downwardly projecting arms of the several bars. For dumping they are

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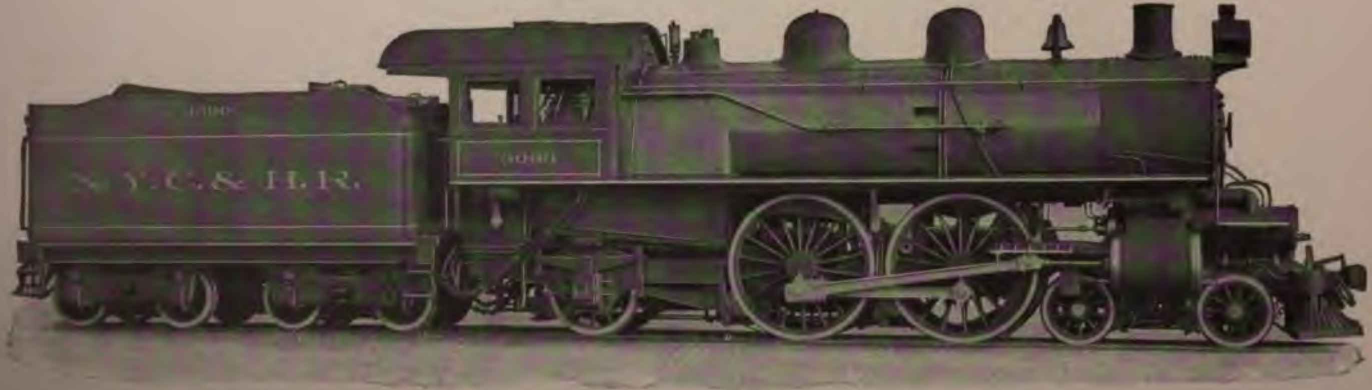


PASSENGER LOCOMOTIVE FOUR-CYLINDER BALANCED COMPOUND.

Built for New York Central and Hudson River Railroad.

turned to an inclined position. At the front end of the firebox there is usually an independent grate consisting of a perforated flat plate. This can be operated separately from the remainder of the grates. It is used when it is desired to clean the fire without dumping the whole. This plate is opened and the clinkers contained in the bed of coals can be pushed through the opening, thus formed, into the ashpan beneath.

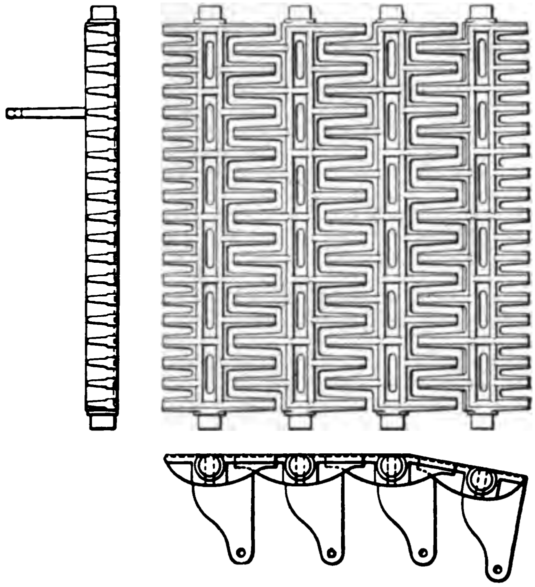


Fig. 19.

A modification of this grate is shown in Fig. 20. It is the grate used on the high-speed express passenger engines of the Pennsylvania Railroad. The bars extend transversely across the firebox, the fingers being 10 inches long measured from the end of one to the end of that opposite to it. The bars and the spaces between them are $\frac{7}{8}$ inch wide. At the front end of the firebox there are two dead plates, which occupy 33 inches, measured in the direction of its

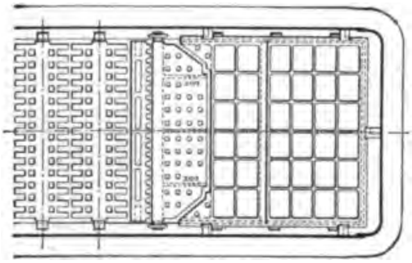


Fig. 20.

length, and back of these is a perforated drop plate 14 inches wide, which can be turned so as to dump the fire into the ashpan. The grate-bars are carried by bearing-bars bolted to the bottom of the mud ring. Special pains have been taken to close all openings around the sides of the firebox so as to prevent cold air from entering at such places. The object of this is twofold; to keep the cold air away from the firebox plates, and to keep the fire away from them, as contact with the cold plates always has the effect of checking combustion. In these grates the bearing-bars stand away from the sides of the firebox. In order to close the crevices which are thus left, cast-iron blocks are made which fit in between the bars and the plates, with a flange or head which laps over the top of the bar. In some cases inclined plates are fastened to the mud-ring and bear against the sides of the firebox, and have joints formed by grooves in the plates filled with asbestos. This makes them almost air-tight.

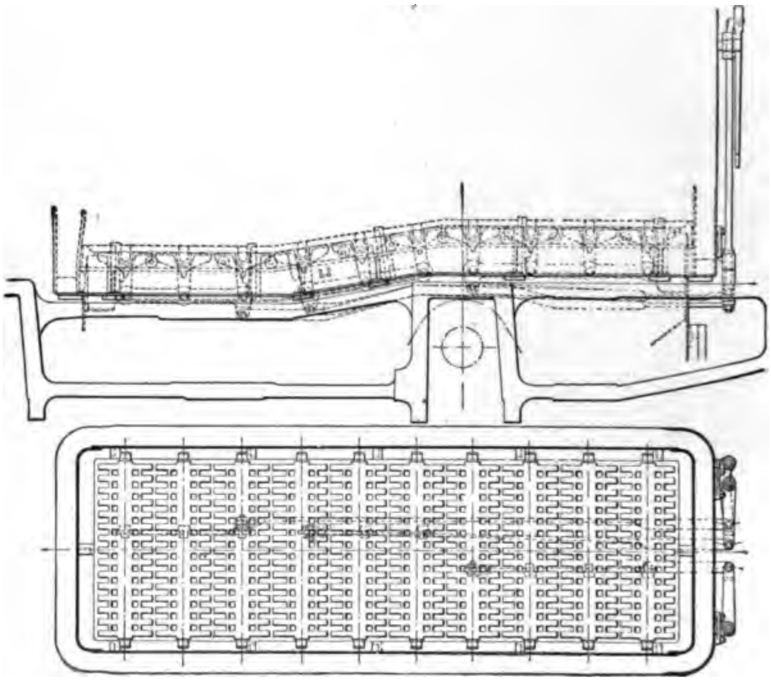


Fig. 21.

A modification of these grates is used for anthracite coal. It is shown in Fig. 21. Here the grates occupy the full length of the firebox. They are divided into three sections, any one of which can be moved by itself. These bars have fingers $10\frac{5}{8}$ inches long and $\frac{3}{4}$ inch wide, with spaces $1\frac{1}{16}$ inches wide.

In the burning of anthracite coal, water grates are extensively used. The usual method of construction is shown in Fig. 22. The grate is formed of a tube *a* that is expanded into a ferrule in the back sheets of the firebox. It is inclined from the back down to the front so as to insure a circulation of water. Opposite the back opening a plug is screwed into the outer sheet. The hole for this plug affords a means for cleaning the tube and also for inserting it in position. At the front end the tube is usually screwed into the tube sheet.

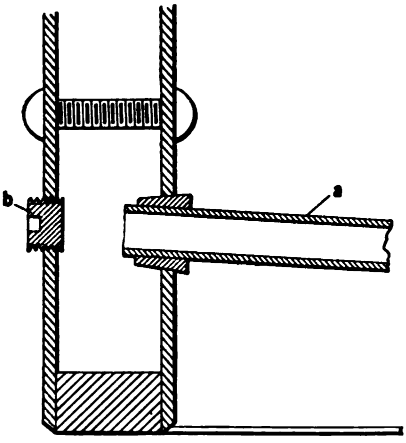


Fig. 22.

Water grates are rarely used alone. They are usually spaced some distance apart and between them plain bars are spaced. These bars pass through tubes expanded into the sheets of the

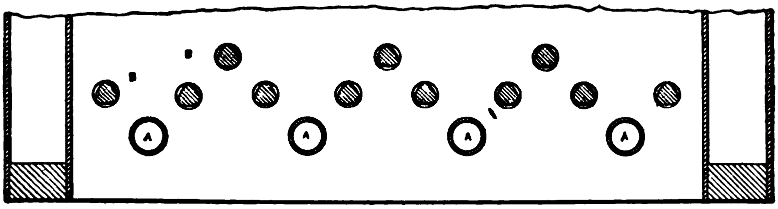


Fig. 23.

back water leg. By turning them the fire may be shaken and by withdrawing them it may be dumped. A cross section of a common arrangement of the water tubes and bars is given in Fig. 23. In this A represents the water tube and B the grate bars. It will be seen that by turning the bars the bed of the fire will be disturbed and the ashes freed; while, by withdrawing the bars, any portion of the fire can be dumped.

Coke has been used for many years as a locomotive fuel in Europe. Recently it has been introduced in this country. Fig. 19 shows a form of cast-iron grate that has been sucessfully applied both for coke and bituminous coal. It greatly facilitates the burning of coke on these grates if a jet of steam be introduced into the ashpan beneath. This cools the grates, thus preventing clinkers from adhering and protecting the grates from melting. A better form of grate for burning coke is shown in Fig. 24. This grate is formed by the use of water bars B running lengthwise the firebox and spaced about 6¼ inches from center to center. These water tubes may be horizontal when the construction of the firebox demands it, but it is preferred that they should be on an incline from the front up to the back. They have an outside

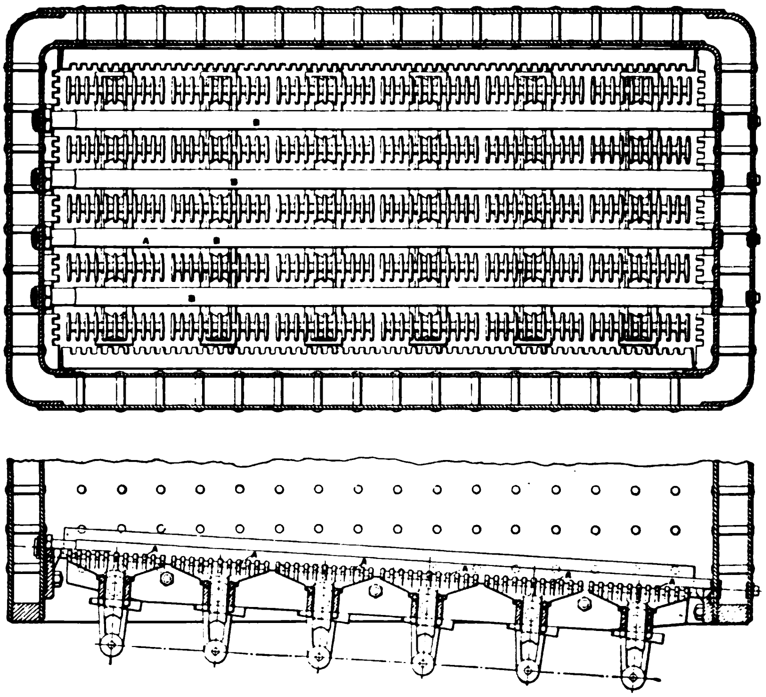


Fig. 24.

diameter of 2 inches, are screwed into the back tube sheet and are held by a bushing screwed into the back sheet of the firebox.

Between the tubes there is a series of rocking grates A, that are also shown in detail in Fig. 25, so arranged that each short section with a length of about 10½ inches can be removed and replaced in case it is injured. The rockers are provided with pockets into which the short grates are dropped. These rockers lie below the water bars where they are well away from the fire, and the fingers are so designed that the maximum of air space is obtained where there are no heavy sections of metal to become heated, the circulation of air having a tendency to keep the parts in contact with the fire cool. These grates are easily rocked; they are of such shape that they readily break the layers of clinkers as may have formed above them, and there is an ample opening between them when they are tipped, to allow the broken masses of clinkers to fall into the ashpan. The grates have proven themselves very efficient in service.

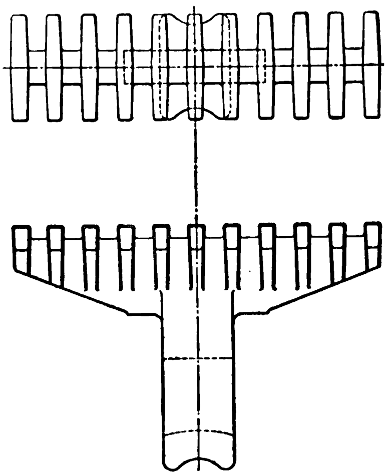


Fig. 25.

Ashpans are suspended beneath the firebox for the purpose of catching and carrying the ashes and coals that may drop between the grate bars. They are made of sheet steel. Fig. 26 is a longitudinal section of an ashpan that is ordinarily used on fireboxes that lie between the axles of the engine. It is provided at each end with a damper *a* hinged at the top, and which may be opened and set in any desired position in order to regulate the flow of air to the fire.

When the firebox lies above the axles the ashpan must be cut away for the passage of the same. It is then divided into hoppers, as shown in Fig. 27.

Dampers. It is quite important that the dampers of locomotive ashpans should be in good condition and capable of regulating the flow of air. For many years the type shown in Fig. 26 was almost universally used in this country. Recently, however, a damper capable of better adjustment and one not as likely to become warped, has been used. Such a damper is shown in Fig. 27. In this type the dampers are placed upon the front face of the ashpans and are raised and lowered by the combination of levers. For example, the lifting of the bar *a* turns the bell-crank *d*, and pulls the connections *cc*, which turn the forward bell-crank *b*. The latter, by means of the connection *e*, raises the damper *f*, and by setting the bar *a* in the proper notch any desired width of damper opening can be maintained. In like manner another bar turning the bell-cranks *g* and *h* operates the back

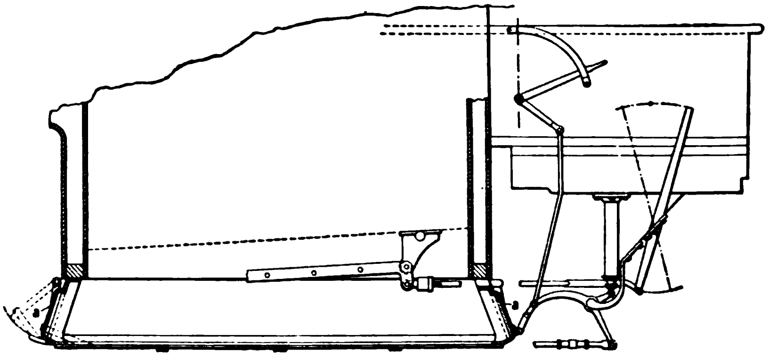


Fig. 26.

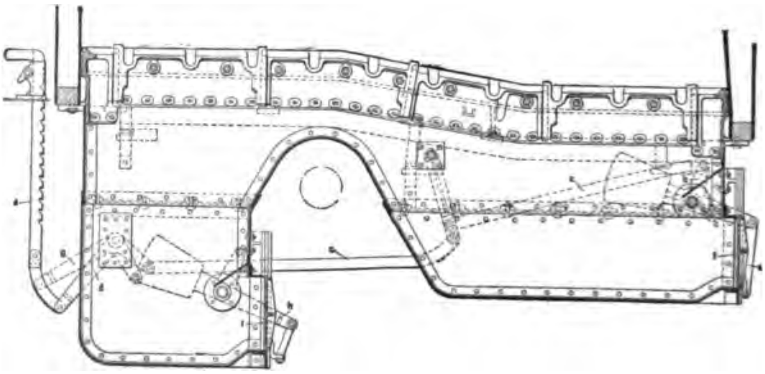


Fig. 27.

damper *i*. Such dampers are best made of cast iron and work in guides so that when closed they are practically airtight.

Fuel. The fuel that is used upon locomotives depends upon local conditions and the cost. The locomotive fuels that are now used throughout the world are oil, tar, peat, lignite, wood, anthracite coal, bituminous coal and coke. The principal fuel used in the United States is bituminous coal. This varies in composition and efficiency according to the mines from which it is taken. Anthracite coal is largely used in the anthracite coal fields. Oil is used in Southern California. Coke is used to some extent in New England and wood on a few small isolated locomotives.

Rate of Combustion. As stated in Chemistry each pound of fuel is capable of giving out a certain definite number of heat units. It is evident, therefore, that the more rapid the combustion the greater the amount of heat produced in a given time. In stationary boilers where the size of the grate is practically unlimited the rate of combustion per square foot of grate area is from 15 pounds to 25 pounds per hour. In locomotives, with the limited grate area available, this rate is many times exceeded, rising, at times, to as much as 200 pounds per hour. This rapid combustion results in a great loss of heat and a fall in the amount of water evaporated per pound of coal. It has been shown that when coal is burned at the rate of 50 pounds per square foot of grate per hour, 8¼ pounds of water may be evaporated for each pound of coal; while, if the rate of combustion is increased to 180 pounds per square foot of grate area, the evaporation will fall to about 5 pounds, a loss in water evaporated per pound of coal of nearly 40 per cent. This loss may be due to a failure of the heating surfaces to absorb properly the increased volume of heat passing over them or to the imperfect combustion of the fuel on the grate, or it may be due to a combination of these causes.

The results of experiments show that, in general, the most efficient furnace action accompanies the lowest rates of combustion, and enforce the general conclusion that very high rates of combustion are not desirable, and, consequently, that the grate of a locomotive should be made large so that exceptionally high rates will not be necessary.

With high rates of combustion the loss by sparks is very serious and may equal in value all the other losses occuring at the grate.

Fig. 28 is a diagram representing the losses that occur, due to an increase in the rate of combustion. The line *a b* shows the amount of water evaporated per pound of coal for the various rates of combustion. Thus with a rate of 50 pounds per square foot of grate per hour, $8\frac{1}{4}$ pounds of water are evaporated. When the rate of combustion is raised to 175 pounds, only about $5\frac{1}{8}$ pounds of water are evaporated. If it could be assumed that the heat developed in the furnace would be absorbed with the same degree of completeness for all rates of combustion, the evaporation would rise to the line *a c*; if, in addition to this, it could be assumed that there were no spark losses, the evaporation would rise to the line *a d*; finally, if in addition to these, it could be assumed that there were no losses by the excessive admission of air or by incomplete combustion, then the evaporation would remain constant for all rates of combustion, and would be represented by the line *a e*.

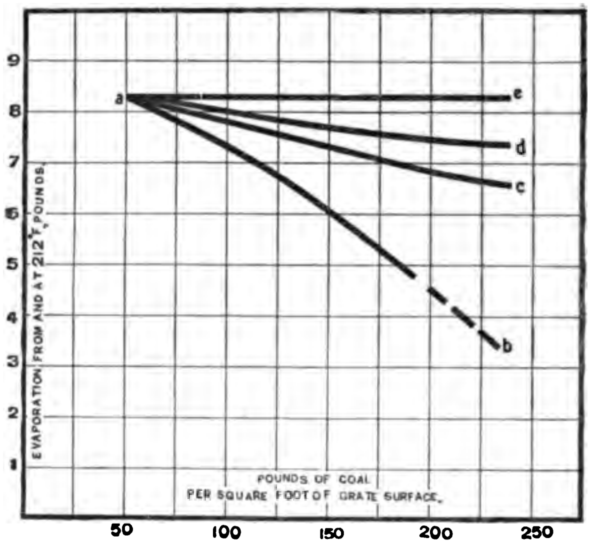


Fig. 28.

That is, with the boiler under normal conditions, the area *a b c* represents the loss occasioned by deficient heating surface, the area *a c d* that occasioned by spark losses and the area *a d e* that occasioned by excessive amounts of air and by imperfect combustion.

The efficiency of the locomotive, from the standpoint of water evaporated per pound of coal, falls off as the rate of combustion per square foot of grate area is increased.

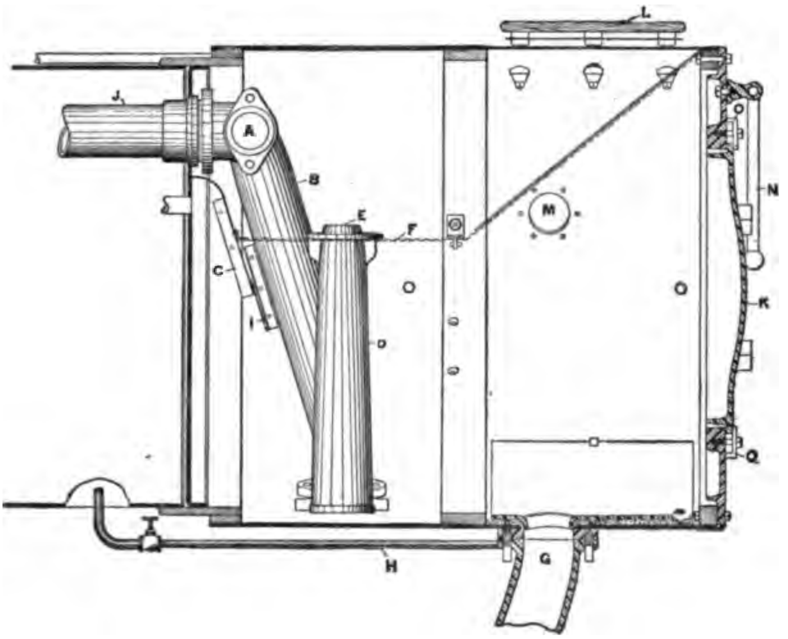


Fig. 29.

NOMENCLATURE.

A—Tee Head
B—Steam Pipe
C—Diaphragm
D—Exhaust Pipe
E—Exhaust Nozzle

F—Netting
G—Cinder Trap
H—Cinder Jet Pipe
I—Sliding Diaphragm Plate
J—Dry Pipe

K—Boiler Front
L—Headlight Stand
M—Hand Hole
N—Hand Rail
O—Door Clamp

The Smoke Box is the chamber in front of the boiler into which the gases of combustion flow from the tubes. It contains the steam pipes, exhaust nozzles, petticoat pipe, diaphragm and netting.

There are two types of smokeboxes in use. One is that shown in connection with the boiler in Fig. 1. This type is rapidly going out of use. The stack is known as the "diamond," and contains the netting to prevent the throwing of sparks. The exhaust nozzles are surmounted by a petticoat pipe that serves to equalize the draught between the top and bottom rows of tubes.

The second form of smokebox is known as the extension front and, in some one of its numerous forms, is almost invariably applied to new engines. An approved form of such a front is shown in section in Fig. 29. The gases issuing from the tubes either strike against the diaphragm plate C and are deflected downward or pass beneath it from the lower rows of tubes. They then turn up and pass through the netting F and out at the stack which is located directly above the exhaust nozzle E.

Exhaust Nozzles. The action of the exhaust jet is that it entrains the gases of the smokebox with it. It does not fill the stack at or near the bottom. Under the conditions of common practice it touches the stack only when it is very near the top. A jet of steam flowing steadily from the exhaust tip, when the engine is at rest, produces a draft that is in every way similar to that obtained with the engine running. The jet acts to induce motion in the particles of gas which immediately surround it and also to enfold and entrain the gases which are thus made to mingle with the substance of the jet itself.

The induced action is by far the most important and is illustrated by Fig. 30. The arrows in this figure represent approximately the direction of the currents surrounding the jets. It will be seen that the smokebox gases tend to move towards the jet and not towards the base of the stack. That is, the jet, by virtue of its high velocity and by its contact with surrounding gases, gives motion to the particles close about it, and these, moving on with the jet, make room for other particles which are farther away. As the enveloping shell of gas approaches the top of the stack its velocity increases and it becomes thinner and thinner as shown in Fig. 30. The vacuum in the stack decreases towards the top. Thus the jet in the upper portion of the stack induces a vacuum in the lower portion, just as the jet, as a whole, induces a vacuum in the smokebox. It will be found that the highest vacuum is near the base of the stack. It is higher than in the smokebox on account of the large volume of gas in the latter. It grows less toward the top of the stack.

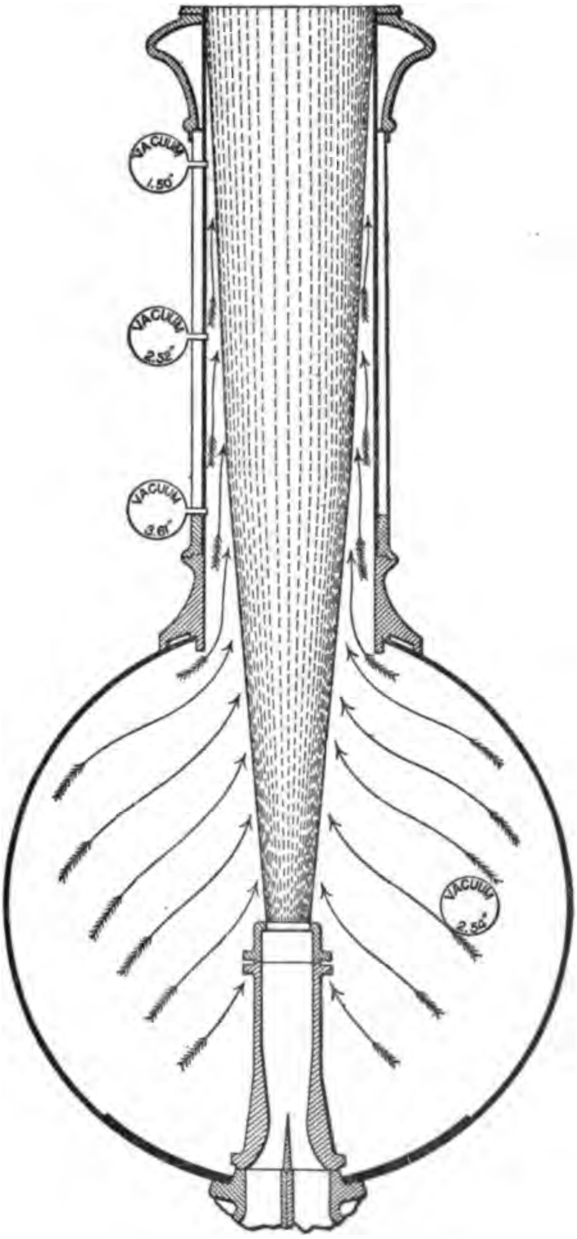


Fig. 30.

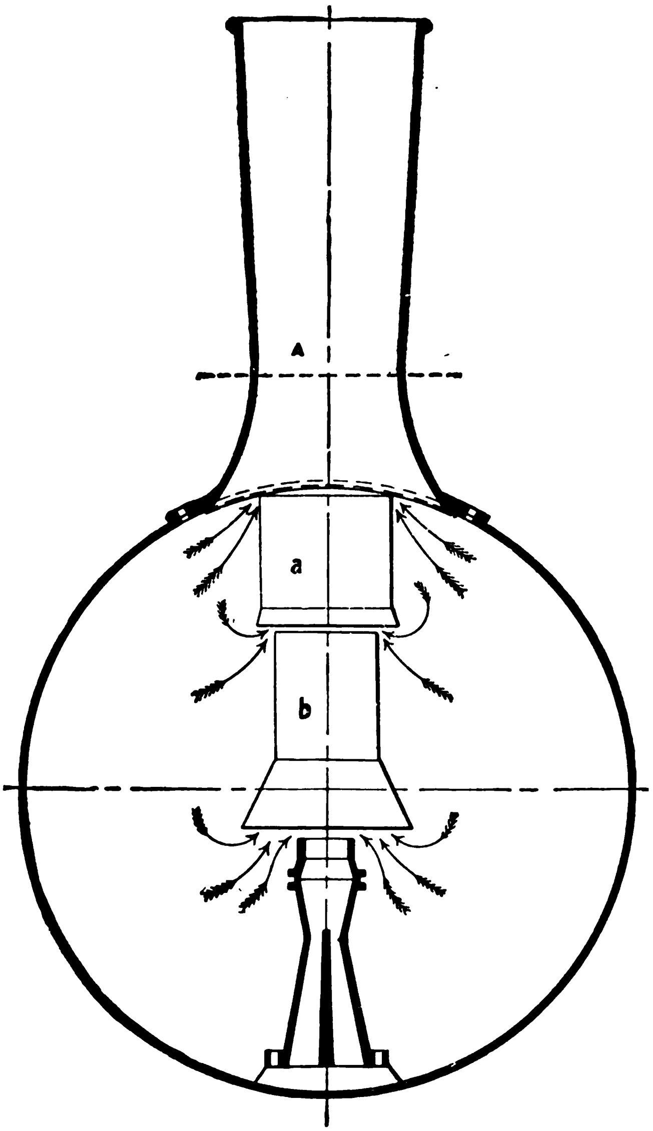


Fig. 32.

be straight as in Fig. 30 or provided with a choke or contraction A as in Fig. 32. Various other forms are used, dependent upon the form of jet issuing from the exhaust nozzles.

The "diamond" stack, Fig. 1, contains a cone G for deflecting sparks and a netting H for preventing the escape of large cinders.

The netting (H of Fig. 1, and F of Fig. 29), is made of iron or steel wire about $\frac{1}{10}$ inch in diameter. The meshes are three or four to the inch. It is sometimes replaced by plates of sheet metal perforated so as to present the same obstruction to the passage of cinders and yet allow as much freedom for the escape of the gases.

Cinder Trap. Unless there is a very careful and accurate adjustment of the diaphragm, netting, nozzles and other parts, cinders will collect in the front end of the extension front. In order to remove them a trap G, Fig. 29, is placed in the bottom. This is closed by a slide that should fit air-tight in its casing so as to prevent an ingress of fresh air into the smokebox. Fresh air not only lowers the vacuum in the smokebox but supplies oxygen for the combustion of the hot cinders that may have accumulated therein.

The Diaphragm C (Fig. 26) is merely a deflector plate set at an angle in front of the tubes. It is formed of two parts, C and I. The upper portion C is fixed while the lower part I is adjustable. The adjustment of the lower portion serves to equalize the draft through the different rows of tubes.

Boiler Fittings. There are a certain number of fittings that must be used on the locomotive boiler in order to enable the engineer to operate it successfully and economically. These fittings consist of the safety valves, whistle, steam gauge, water gauges, blower, throttle valve, dry pipe and injectors.

Safety Valves. The universal practice at present is to use at least two safety valves of the *pop* type upon every locomotive boiler. These valves are placed upon the dome.

The requisites of a good safety valve for locomotive work are that when raised the area for the escape of steam should be sufficient to allow it to escape as rapidly as it is formed; its construction should be such that it will close as soon as the pressure has fallen a predetermined amount below the load.

It should be so designed that it can neither be tampered with nor get out of order.

It must act promptly and efficiently.

It must not be affected by the motion of the locomotive.

These conditions are all met in the valve shown in section in Fig. 33, which is of the Richardson type. In this design the valve *a* rests upon the seat *b b*. The valve is held down by a spindle *c*, the lower end of which rests upon the bottom of a hole in the valve *a*. A helical spring *d* rests on a collar on the

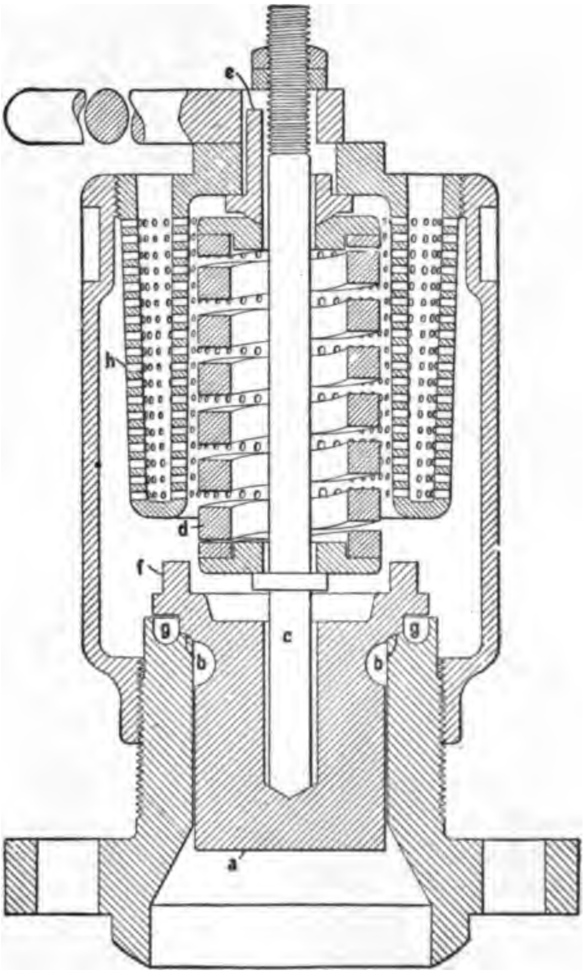


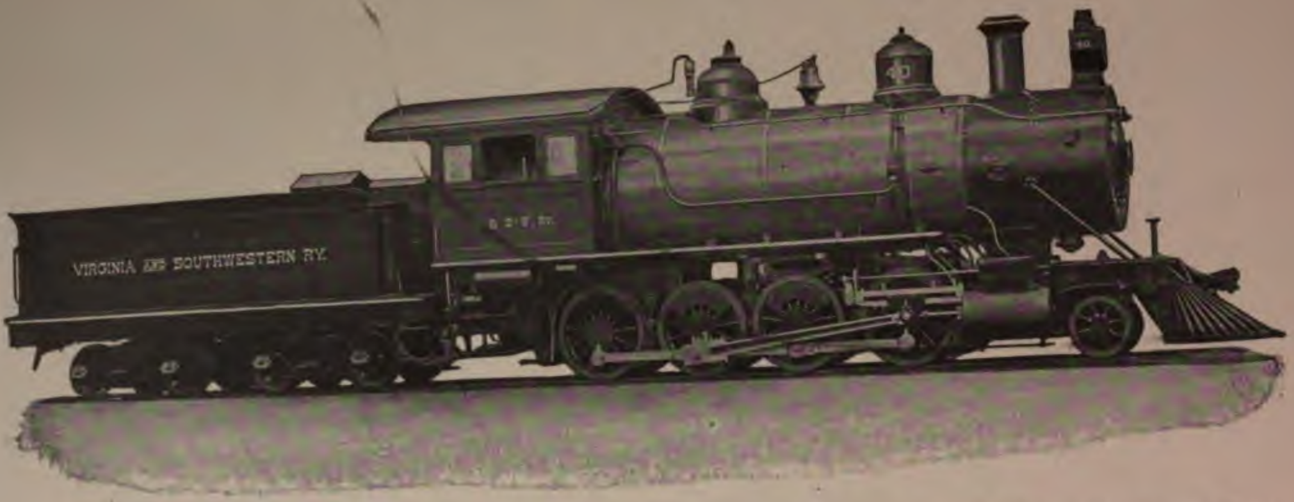
Fig. 33.

spindle. The pressure on the spindle is regulated by screwing the collar *e* up or down in the muffler casing. The valve seat *b b* may be rounded as in Fig. 33 or straight. Outside of the valve seat there is a projection *f* beneath which a groove *g* is cut in the casing. When the valve lifts, this groove is filled with steam which presses against that portion of the valve outside of the seat which, by thus increasing the effective area of the valve, causes it to rise higher and remain open longer than it would without this device. The adjustment of the valve is usually made so that, after opening, it will allow steam to escape until the pressure in the boiler is about 4 lbs. per square inch below the normal.

The U-shaped, perforated casing *h* serves as a muffler to decrease the noise caused by the escaping steam. It does it by breaking the large stream issuing from the main valve up into a number of small jets.

The size of safety valve to be used on steam boilers is regulated, in the case of marine boilers, by the United States Board of Supervising Inspectors, and in case of stationary boilers by various state laws and local ordinances. The rules of the United States Board of Supervising Inspectors are that the lever safety valves attached to marine boilers shall have an area of not less than one square inch to two square feet of grate area and that the seats of all such safety valves shall have an angle of inclination of 45 degrees. Spring loaded safety valves of the *pop* type shall have an area of not less than one square inch to three square feet of grate surface. Except for water-tube sectional boilers carrying a steam pressure of 175 pounds per square inch, the area of the safety valve shall not be less than one square inch to six square feet of grate area.

Neither the general government nor the individual states have, as yet, placed any regulations upon the size of safety valves used upon locomotive boilers. The practice of builders is, however, to use two or three valves whose combined area shall be equal to one square inch to 2 square feet of grate area, with a tendency to make the ratio of grate to valve more rather than less. This is especially true on boilers of the Wootten type where the ratio may be as high as one square inch of valve area to 5



CONSOLIDATION FREIGHT LOCOMOTIVE, BALDWIN LOCOMOTIVE WORKS—Total Weight of Engine, 77 Tons [illegible] AND

[illegible]NDATIONS

square feet of grate. The usual practice is to use 2½ inch or 3 inch valves.

Whistle. The whistle is used for signal purposes and consists of a thin cylindrical bell, A Fig. 31, closed at the top and sharpened at the lower edge. Steam is allowed to escape from a narrow circular orifice B directly beneath the edge of the bell. Part of this steam enters the interior and sets up a series of vibrations therein. The more rapid these vibrations, the higher the tone of the whistle. The tone is affected by the size of the bell and the pressure of steam. The larger the bell, the lower will be the tone; the higher the steam pressure, the higher the tone. In order to avoid the shrill noise of the common whistle, chime whistles are used. In these the bell is divided into these compartments, tuned respectively to the first, third and fifth of the common musical scale, which harmonize and give an agreeable chord.

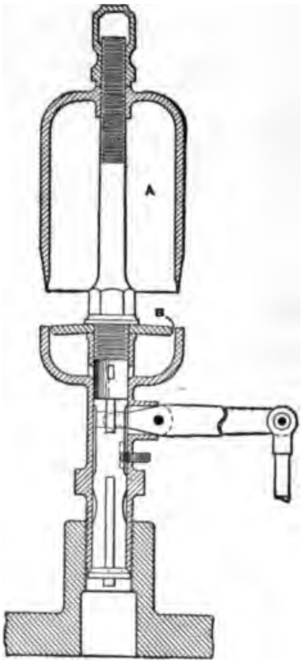


Fig. 34.

Steam Gauges. The use and construction of the steam gauge is fully explained on pages 27 to 30 of Boiler Accessories.

Water Gauges are also fully explained in Boiler Accessories, pages 24 to 27.

The Blower consists merely of a steam pipe leading from, and fitted with a valve in the cab, to the stack where it is turned upward. The escaping steam gives motion to the air therein exactly as already explained for the exhaust and thus induces a draft through the firebox. It is used when the fire is to be forced while the engine is standing.

Throttle Valve. The throttle valve now in universal use is the double seated poppet valve shown in Fig. 35. There are two valves *a* and *b* attached to a single stem. The upper valve *a* is the larger. The lower valve *b* is of such a diameter that it will just pass through the seat of *a*. The steam, therefore, exerts a pressure on the lower face of *b* and the upper face of *a*. As the area of *a* is the greater the resultant tendency is to hold the valve closed. The valve is, therefore, partially balanced. It is, however, usually difficult to open large throttle valves, such as are now used on locomotives with high boiler pressure, and with an ordinary direct form of leverage it is necessary to give a strong, quick jerk to the throttle lever before the valve can be started from its seat. The leverage arrangements shown in Fig. 85 obviate this difficulty. The rod *c* connects with the lever in the cab and communicates its pull to the bell crank *d*, whence it is carried by the stem *e* to the valve. The pivot of the bell-crank is provided with a slotted hole. At the start the length of the lever arm is about 2¼ inches while the long arm is 9½ inches. After the valve has been lifted from its seat and is free from the excess of pressure on *a*, the projecting horn A on the back of the bellcrank comes in contact with the bracket B on the side of the throttle pipe and the crank takes the position shown by the dotted lines in the figure. The end of the horn then becomes the pivot and the length of the short arm of the lever is changed to 9½ inches and of the long arm to about 11½ inches.

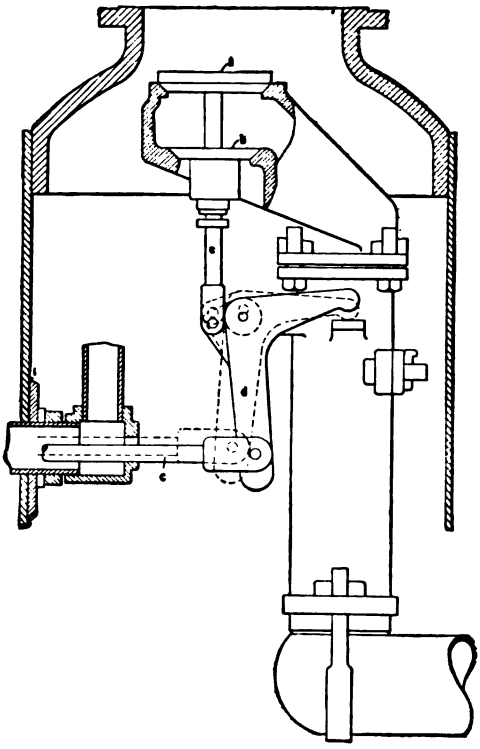
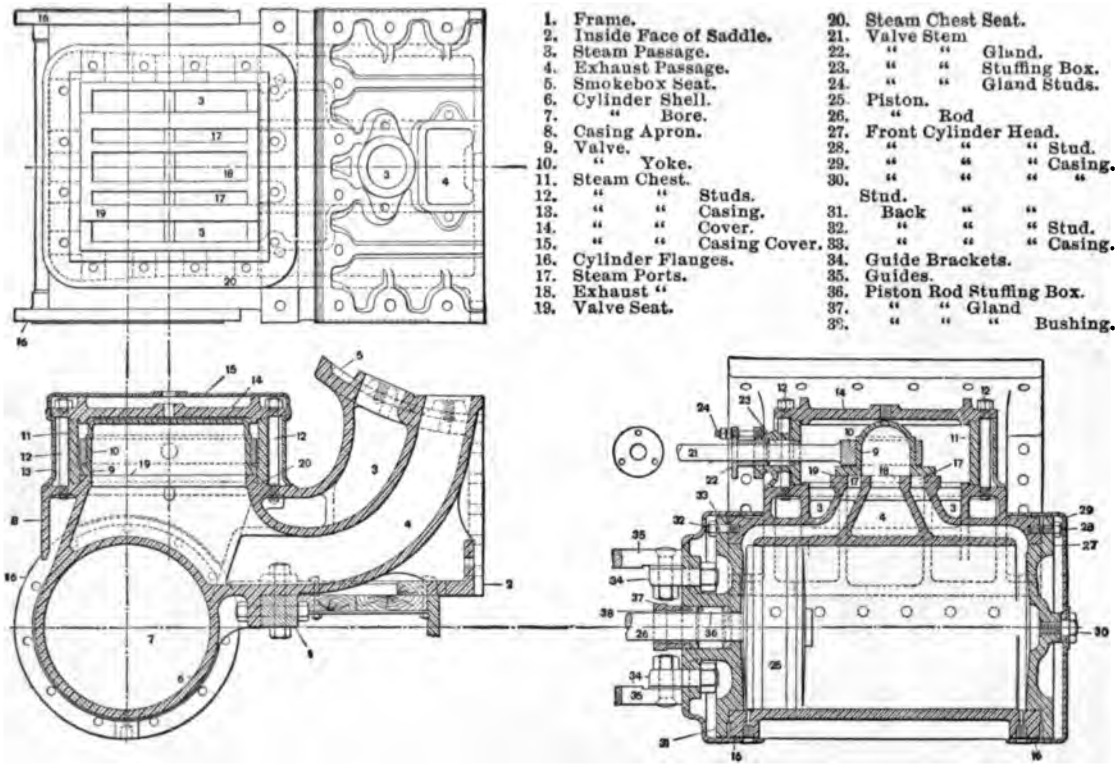


Fig. 85.

The Dry Pipe is the name given to the pipe M shown in

Fig. 1. It leads from the throttle valve to the front end of the boiler. When the throttle valve is closed it is subjected to the pressure of steam upon the outside, and must be strong enough to withstand it. It is made of wrought or cast iron. Since the



1. Frame.
2. Inside Face of Saddle.
3. Steam Passage.
4. Exhaust Passage.
5. Smokebox Seat.
6. Cylinder Shell.
7. " Bore.
8. Casing Apron.
9. Valve.
10. " Yoke.
11. Steam Chest.
12. " " Studs.
13. " " Casing.
14. " " Cover.
15. " " Casing Cover.
16. Cylinder Flanges.
17. Steam Ports.
18. Exhaust "
19. Valve Seat.
20. Steam Chest Seat.
21. Valve Stem
22. " " Gland.
23. " " Stuffing Box.
24. " " Gland Studs.
25. Piston.
26. " Rod
27. Front Cylinder Head.
28. " " " Stud.
29. " " " Casing.
30. " " " "
Stud.
31. Back " "
32. " " " Stud.
33. " " " Casing.
34. Guide Brackets.
35. Guides.
36. Piston Rod Stuffing Box.
37. " " Gland
38. " " " Bushing.

Fig. 36.

introduction of high steam pressures wrought iron is generally used. The diameter of the dry pipe depends upon that of the cylinders. It should be of such a diameter that the area of its cross section is equal to at least one-twelfth the combined sectional areas of the two cylinders.

Injectors are now universally employed for delivering the feed-water to the boiler. Two injectors are always used, either one of which should have a capacity sufficient to supply the boiler with water under ordinary working conditions. They are located one on either side of the boiler. The construction and action of the injector is explained on pages 45 to 47 of Boiler Accessories.

The Cylinder is one of the most important of the details of a locomotive engine. It is invariably made of cast iron. The design varies somewhat with the builder, though in a general way that shown in Fig. 36 is the type ordinarily used in modern engines. It is known as the cylinder with the half saddle cast on. The saddle consists of that part extending from the frame 1 out to the face 2, which is bolted to the corresponding saddle for the other side of the engine. These faces are accurately planed to fit to each other, and to the frame. The steam 3 and exhaust passages 4 are cast in the saddle, and in the best designs, the former are protected by air spaces for the prevention of the radiation of heat. The casting is so made that, by turning it end for end, one cylinder can be used upon either side of the engine.

Cylinder specifications usually call for a metal that shall be fine and close-grained, and as hard as can be worked. The securing of the proper proportions of a cylinder for a locomotive is a matter of great importance in locomotive designing. They must be large enough so that with the maximum steam pressure of the boiler they can always turn the driving wheels when the locomotive is starting, but their size should not be much greater than that needed for that purpose, otherwise the pressure on the pistons will be apt to slip the wheels on the rails. The maximum force of the cylinders should, therefore, be equal to the adhesion of the wheels to the rails. This may be assumed to be equal to one-quarter of the weight on the driving wheels. The maximum mean effective piston pressure may be taken to be 90 per cent. of the boiler pressure.

As the length of the stroke is usually fixed by the convenience of arrangement and the diameter of the driving wheels, the determination of the size of the cylinder usually consists in a calculation of its diameter. In order to make this calculation, the diameter of the driving wheels, the weight on the driving wheels, the boiler pressure and the stroke of the piston must be known. With this data the diameter of the cylinder can be calculated as follows:

Divide the weight on the driving wheels by four (this gives the adhesion) *and multiply by the circumference of the driving wheels* (thus obtaining the amount of work that the wheels are capable of transmitting in one revolution). *Then multiply 90 per cent. of the boiler pressure* (or the maximum mean effective pressure on the pistons) *by four times the stroke of the pistons* (or the total distance traveled by the two pistons in one revolution of the wheels.) *Then divide the first product by the second and the quotient will be the area of each piston in square inches.*

From the area the diameter can be readily obtained by the rules given in Mensuration.

Putting the above rule in the shape of a formula, we have:

$$A = \frac{\frac{W \times C}{4}}{.90\,P \times 48} = \frac{W \times C}{14.4\,P \times S}$$

or

$$A = \frac{W \times D \times 3.1416}{14.4\,P \times S} = \frac{.218\,W \times D}{P \times S}$$

in which

A = area of each piston in square inches.

W = weight on driving wheels,

C = circumference of driving wheels = 3.1416 D,

D = diameter of driving wheels in inches,

P = boiler pressure in pounds per square inch,

S = stroke of piston in inches.

In order to make a practical application of this rule, let us take an engine in which the weight on the driving wheels is 95,000 pounds; the diameter of the driving wheels is 62 inches; the boiler pressure 180 pounds per square inch and the piston stroke is 24 inches. The last formula then becomes:

$$A = \frac{.218 \times 95{,}000 \times 62}{180 \times 24} = 297.2 \text{ sq. in.}$$

or the diameter of the cylinder should be 19.44 inches. Such a cylinder would in practice probably be made 19 inches in diameter.

ILLUSTRATIVE EXAMPLES.

1. What should be the diameter of the cylinders of a locomotive in which the weight on the driving wheels is 89,000 pounds; the diameter of the driving wheels is 50 inches; the boiler pressure is 150 pounds per square inch, and the piston stroke is 24 inches? *Ans.* $18\frac{1}{2}$ inches.

2. What should be the diameter of the cylinders of a locomotive in which the weight on the driving wheels is 54,000 pounds; the diameter of the drivers is 62 inches; the boiler pressure is 145 pounds per square inch, and the piston stroke is 24 inches?

Ans. $16\frac{3}{8}$ inches. Use 16 inches.

3. What diameter of driving wheels can be used upon a locomotive where the weight on the driving wheels is 110,400 pounds; the boiler pressure is 180 pounds per square inch; the diameter of the cylinder is 19 inches and the stroke of the piston is 24 inches?

Ans. $50\frac{7}{8}$ inches. Use 51 inches.

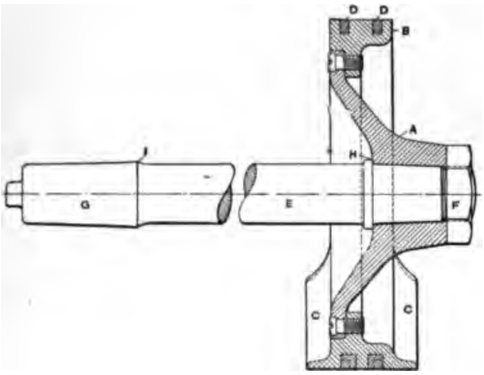


Fig. 37.

These conditions are not always followed where cylinder dimensions are based upon a short cut-off and the expansive use of steam.

With the weight and diameter of the driving wheels together with the steam pressure given, a figure will be obtained from the above formula that will equal the area of the piston multiplied by the stroke. These two dimensions can then be settled according to convenience. So far as the power of the engine is concerned it makes no difference whether the cylinders have a diameter of 16 inches with a piston stroke of 24 inches, or a diameter of 17 inches and a piston stroke of about 21.26 inches.

The difference is that, with the cylinder of the larger diameter, the pressure on the piston, and consequently on the crank-pin, and the stress on the parts would be greater than with the smaller cylinder.

Piston and Piston-rod. As the piston is called upon to do the initial work of the engine it must fulfill two requirements: it must have the requisite strength and it must have a steam-tight joint with the inner wall of the cylinder. In order to meet the second requirement it is necessary that a packing shall be inserted in the rim. Fig. 37 shows an approved construction of piston and rod. The body of the piston A is a steel casting of the dished type. To this is bolted the rim B, made of cast iron. At the bottom the rim may be widened as at CC, so as to secure a greater wearing surface. Two grooves are cut in the rim and into these are sprung the two rings D D. These rings are held out against the walls of the cylinder by their own resilience. Steam is prevented from leaking past the joint where they are split by a cap as shown at the bottom of the engraving. The piston-rod E is made of steel and is held in the piston by the nut F, which draws the rod tightly into the taper fit in the piston. At the crosshead end, the taper seat G is drawn tightly into the crosshead by a key that is not shown. In calculating the strength of the piston-rod it may be considered as a solid circular column with a length equal to the distance from the cross-head to the piston, that is called upon to carry a load equal to the total steam pressure on the piston. In Fig. 37 let the distance from H to I be 37 inches and the diameter of the piston be 19 inches. The diameter of the piston-rod may be calculated by the following formula.

$$A = \frac{P}{S} + \frac{P q l^2}{S G^2}$$

in which

A = area of metal in square inches,
P = breaking strength of column,
S = working strength of the metal,
$$G^2 = \frac{d^2}{16}$$
d = diameter of piston-rod,
q = a constant,
l = length of rod in inches,
S^1 = ultimate strength of the metal.

As the load is not a static one and as the piston-rod is subjected to very severe jars and shocks, an exceedingly high factor of safety must be allowed. This should range from 20 to 25.

Where S is used in the formula it should therefore be from
$$\frac{S^1}{20} \text{ to } \frac{S^1}{25}.$$

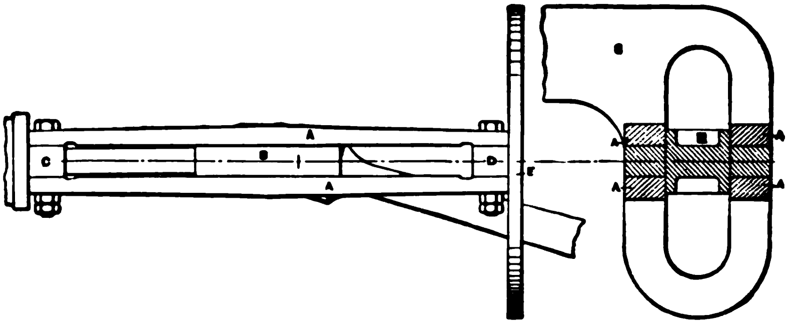


Fig. 38.

In Fig. 37 let a factor of safety of 25 be used. P then becomes the load on the piston or its area multiplied by the steam pressure, which, taken at 180 pounds per square inch becomes

$$P = 180 \times 283.529 = 51{,}035.22,$$

q may be taken at $\frac{1}{25{,}000}$

S = the ultimate strength of the metal divided by 25 $= \frac{150{,}000}{25} = 6{,}000.$

The equation then becomes

$$A = \frac{51,035.22}{6,000} + \frac{51,035.22 \times 1369}{6,000 \times 25,000 \times \frac{d^2}{16}}$$

$$\text{as } A = \frac{\pi d^2}{4}$$

Then

$$\frac{\pi d^2}{4} = 8.50587 + \frac{69,867,216.18}{9,375,000 d^2}$$

and

$$d^2 = 10.829 + \frac{9.488}{d^2}$$

$$d^2 = 11.642$$

$$d = 3.41$$

Such a rod would probably be given a diameter of $3\frac{1}{2}$ inches in order to allow for wear.

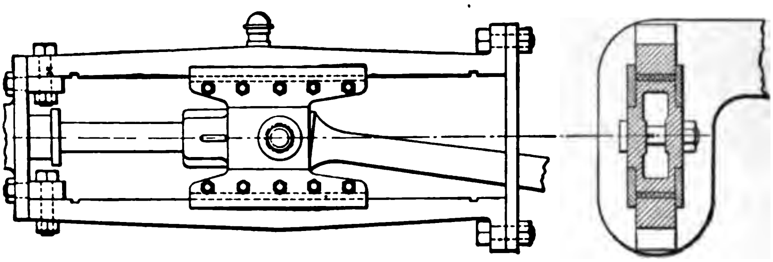


Fig. 39.

ILLUSTRATIVE EXAMPLES.

1. What should be the diameter of a piston-rod 38 inches between crosshead and piston; piston 18 inches diameter; steam pressure 160 pounds per square inch; factor of safety 22, other data as above? Ans. 2.9 inches. Use 3 inches.

2. What should be the diameter of a piston-rod for a 17-inch cylinder; steam pressure 150 pounds per square inch; distance from crosshead to piston 36 inches; factor of safety 24, and other data as before? Ans. $2\frac{3}{4}$ inches.

Crosshead and Guides. There are a variety of forms of crossheads which are adapted to various types of engines. These may be divided into three general classes known as the four-bar, two-bar and one-bar guides. The four-bar guide was at one time very extensively, if not universally used. It is shown in side elevation and section in Fig. 38. This form of guide and crosshead consists, as its name indicates, of four bars, A, forming the guides with the crosshead, B, between them. The guides may be made of steel, wrought iron or cast iron. When wrought iron is used, it is usually case-hardened. The crosshead is usually of cast iron and is provided with wearing surfaces of babbitt pinned to the cast iron or of brass in the form of gibs. The guides are bolted to guide blocks C and D that are held by the cylinder head and guide yoke E respectively. The guide yoke E serves to hold the back end of the guides and is itself securely bolted to the frames and is usually also provided with a brace that is riveted to the boiler. The guide yoke is of steel.

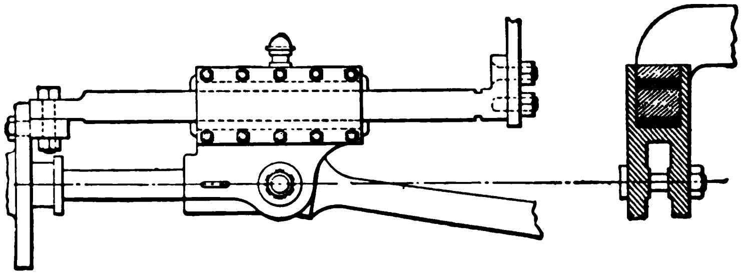


Fig. 40.

The two-bar guide with its crosshead is shown in Fig. 39.

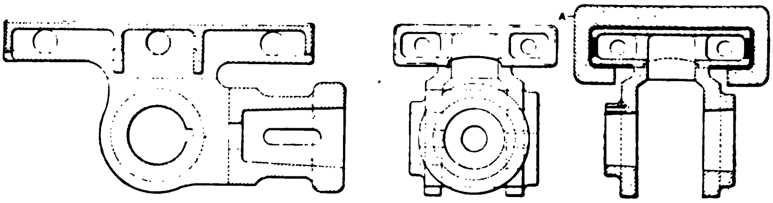


Fig. 41.

The principal difference, aside from the number of bars, lies in the vertical distance between them. The advantages of this type are that the parts are more accessible for adjustment and repairs, and that a steel wrist-pin can be put in the crosshead. In the crosshead of the four-bar type the wrist-pin is cast in solid with the crosshead and must, necessarily, be of the same material. The two-bar crosshead is usually made of a steel casting with wrought iron or steel side plates and pins, and is fitted with brass gibs for the wearing surfaces.

The one-bar guide is shown in Fig. 40. The materials used in this construction are the same as in the case of the two-bar guides. This crosshead is also fitted with brass gibs for the wearing surfaces. The advantage of this form of guide is that it can be used on locomotives having small driving wheels without placing one of the guides near the ground where it will be apt to be rapidly worn by the dirt. A disadvantage arises from the tendency of the crosshead to tilt and thus put a bending stress upon the piston rod. Such a stress is apt to break the rod at the point where it enters the crosshead.

Another form of crosshead is shown in Fig. 41. This is an improved form in which exceedingly large bearing surfaces are obtained. These are also well protected from the dust. The guide is shaped as shown in the section at A. It will be seen that the bearing surface on the top of the crosshead is very large. This is as it should be because, when an engine is running forward, the angularity of the connecting rod tends to lift the crosshead on both the forward and backward strokes of the piston.

Connecting Rods are now invariably made of steel and of an I section. The reason for the use of this section is that it makes it possible to distribute the metal to the best advantage and thus obtain the strongest rod with the least weight. Fig. 42 illustrates a design of connecting rod used upon a modern high-speed express passenger locomotive. The brasses A at the crosshead end are adjusted by a wedge B drawn across the rod and bearing against the block C which, in turn, has a bearing against the brass A. The reason for using a key moving across the rod is the lack of space wherein to move it vertically.

At the crank-pin end the rod is made with an open jaw composed of the top and bottom straps D and E. These are connected at the back by a *filler* F. The brasses are adjusted by a key driven vertically and held by two set screws. In this case the oil cups are forged on solidly with the rods and are closed by caps screwed on.

Parallel Rods are also made with an I section and for the same reason as in the case of connecting rods. The side rods are fitted with brass bushings, A A of Fig. 43, at the ends. These bushings are pressed into position and are sometimes held from turning by a set screw. These brasses have no means of adjustment and, when worn, they must be replaced by new ones bored to fit the pin.

The stresses to which parallel and connecting rods are subjected are very severe. They are of a twofold character; one is due to the direct thrust of the piston, the other is the centrifugal force due to the rotary motion of the parts. The latter has a greater influence upon the parallel or side rod than upon the connecting rod. The former has the greater influence upon the connecting rod. In an eight-wheeled locomotive with four wheels coupled, the parallel rod is supposed to transmit one-half the thrust of the piston to the rear wheel.

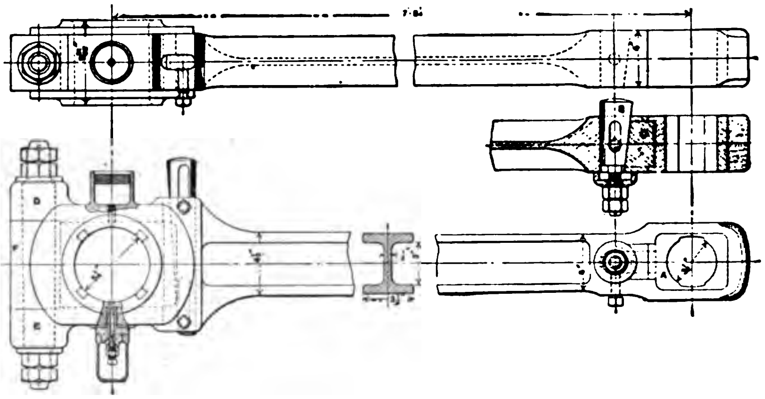


Fig. 42.

The thrust of the piston upon the rod may be expressed by the formula

$$T = \frac{P\,A}{2}$$

in which

T = the thrust on the parallel rod.
P = steam pressure in pounds per square inch.
A = area of piston.

It is, however, the centrifugal action that puts the greatest stress on the rod. A calculation of this stress can be made by the use of the formula for calculating centrifugal force given in textbooks on Mechanics. The rod may be considered as a beam supported at each end and uniformly loaded.

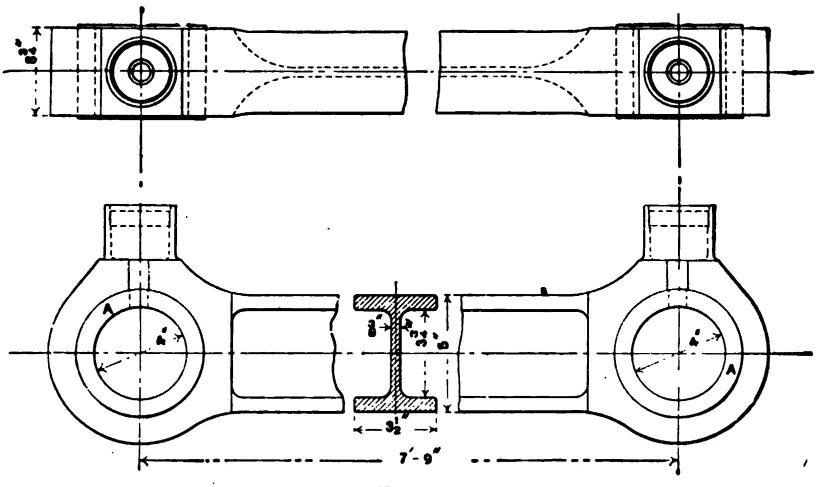


Fig. 43.

a jaw at one end by which it serves to connect the reversing lever H and the lifting shaft K of Fig. 1.

The Lifting Shaft shown at K, Fig. 1, consists of a shaft held in brackets, that are usually bolted to the frames, to which are welded three arms: the vertical one to which the reach rod is attached and two horizontal ones from which the links are suspended.

The Link Hanger M is a flat bar with a boss on each end. It carries the link by means of a pin attached to the link saddle as shown in Fig. 3.

The Link is an open device, held by the saddle and fitted with connections for the eccentric rods. It is made of steel or wrought iron and is usually hardened on the wearing surfaces.

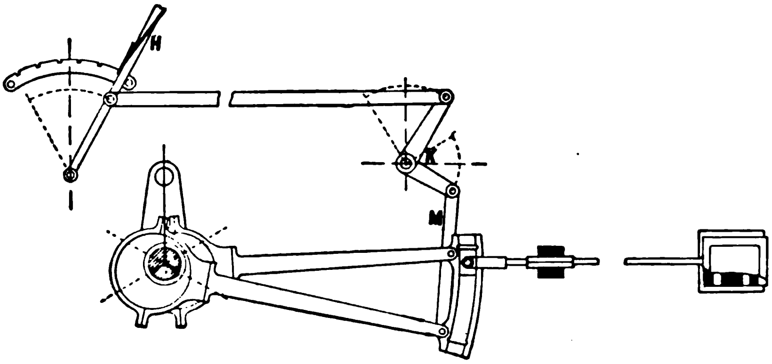
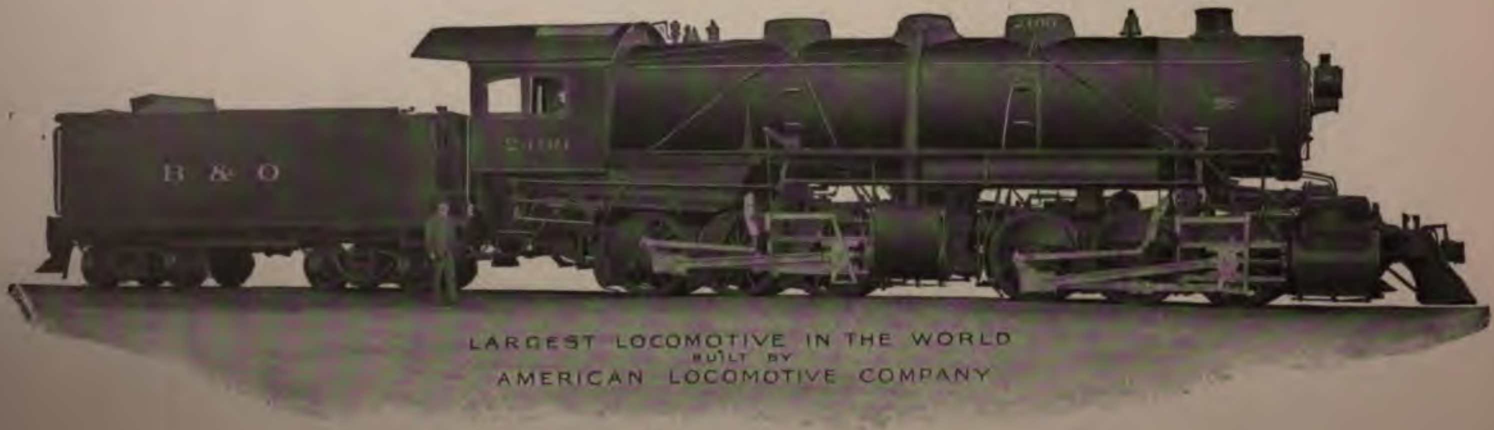


Fig. 1.

The Eccentrics are usually of cast iron.

The Rocker Arm, Fig. 7, consists of a shaft to which two arms are welded or cast. The lower arm is attached to the link block, and the upper to the valve stem.

Setting the Valves. This is a comparatively simple operation but one requiring some care. In the first place it may be stated that no link motion can be arranged to give equal cut-off at all points for both strokes of the piston. The most satisfactory arrangement is one that provides for an equalization of the lead and cut-off at mid-gear, which will cause a variation of cut-off of from $\frac{1}{2}$ to $\frac{3}{8}$ of one per cent. in the full gear point of cut-off and at other points, which is due to the slip of the link block, angularity of the rods, etc.



FREIGHT LOCOMOTIVE FOUR-CYLINDER ARTICULATED COMPOUND.
American Locomotive Company.

In setting the valves upon a locomotive, some means must be provided for turning the driving wheels. The main driving wheels (those to which the connecting-rod is coupled) are usually raised and set upon rollers, which can be turned by a hand lever or an electric motor. The drivers can thus be turned without moving the engine. Where such a set of rollers are not available the engine may be moved to and fro over the track by using pinch bars.

The side rods are taken down and the connecting-rods put in position as the first step. Then make an accurate measurement of the outside lap of the valve. Next set the valve in its central position on its seat. That is to say, so that the lap on each side extends an equal distance beyond the ports. When this has been done, make a small center-punch mark on the flange of the stuffing box, as at *a* Fig.4, and with a fixed tram, shaped as *b*, make a punch mark, as at *c*, on the valve stem. It will always be possible then to set the valve in the central position, even though the steam chest cover may be on.

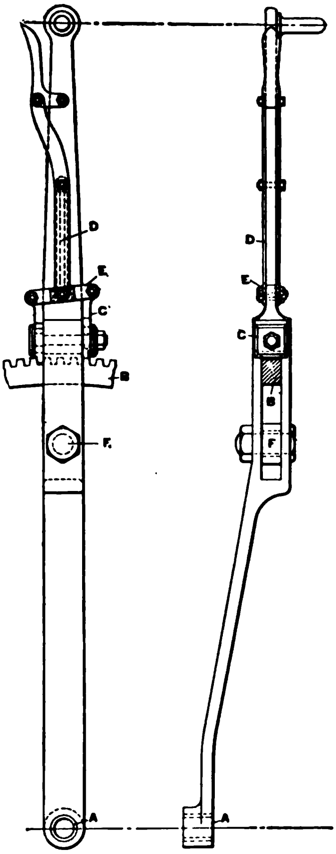


Fig. 2.

Next adjust the length of the valve rod. To do this first set the upper arm of the rocker so that it stands exactly vertical if the valve seat is horizontal. If the valve seat is inclined the arm must be set at right angles to the surface of the seat. Then adjust the length of the valve rod so that it will unite the rocker and the valve without disturbing the position of either.

Next fasten both eccentrics in any position on the axle and connect the eccentric-rods to the straps and the link, which must

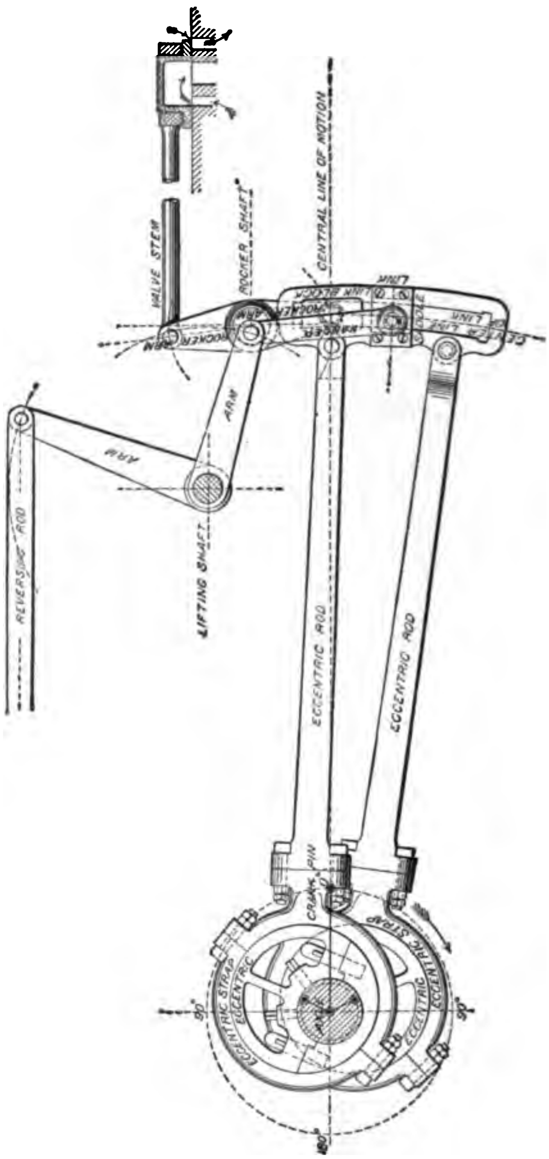


Fig. 8.

be suspended from the lifting arm with the reach rod and reversing lever in place. Drop the reversing lever into the extreme forward position and turn the drivers, noting whether the valve has an equal amount of travel on each side of its central position.

If it has not, adjust the length of the forward or upper eccentric-rod until such an equalization is obtained. If the valve travels more to the front than to the rear of the engine the eccentric-rod is too short and must be lengthened. If the excess of travel is to the rear the rod is too long and must be shortened. Then raise the link to the extreme backing position and perform the same operation on the lower or backing eccentric-rod. In order to check the accuracy of the work the links should again be dropped into the extreme forward position, and another test of the valve travel made. The best method of measuring this travel is to use a tram and scribe a line on the valve stem at the extreme points of travel, and measure from these lines to the center punch mark, *c* Fig. 4, already referred to.

The valve motion is now ready for the setting of the eccentrics. To do this, first set the engine crank on the dead center. The best way to do this is to make a mark on the guides at the extreme point of travel of the crosshead. Then turn the engine back and come ahead again until the crosshead is within a half inch of its extreme point of travel. With a tram, as shown in Fig. 5, resting upon some fixed point of the engine, locate the point *a* on the side of the driving wheel. Then turn the engine ahead until the crosshead has passed the extreme point of travel and reached the same mark as before, when a second point *b* is to be located at the same distance from the center of the axle as the point *a*. With a pair of dividers locate the point *c* midway between *a* and *b*. Then turn the engine until the tram point rests upon the point *c*, when the engine will be upon the center.

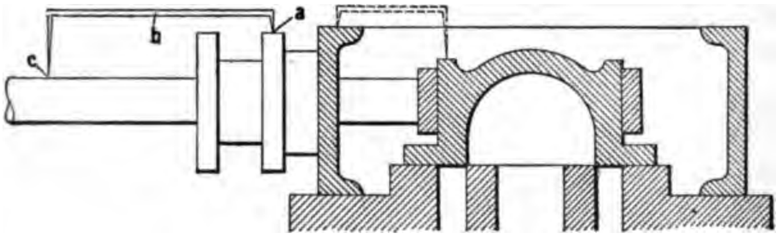


Fig. 4.

The reason for not setting the engine on the center by the crosshead is that the crank may move through an appreciable angle while passing the center and the motion of the crosshead be imperceptible. The method given locates the center exactly. The other center should be established in the same way.

In setting the eccentrics always turn the engine in the direction in which it is to move under the influence of the eccentric being set. This obviates a variation in the action of the valve due to lost motion in the parts.

The engine being now placed upon the center, drop the link into its extreme forward position and loosen the eccentric. In the case of locomotives with a rocker shaft having arms extending in opposite directions, the eccentric follows the crank. Turn the eccentric accordingly until the valve is opened by the desired amount of lead. Then fasten it in position. Now raise the link to the backing position and set the other eccentric in the same manner. Again drop the link to the forward position and see whether or not the lead has been changed by the adjustment of the backing eccentric. If it has, readjust the forward eccentric to suit the case, which means re-setting it under the same rule as before.

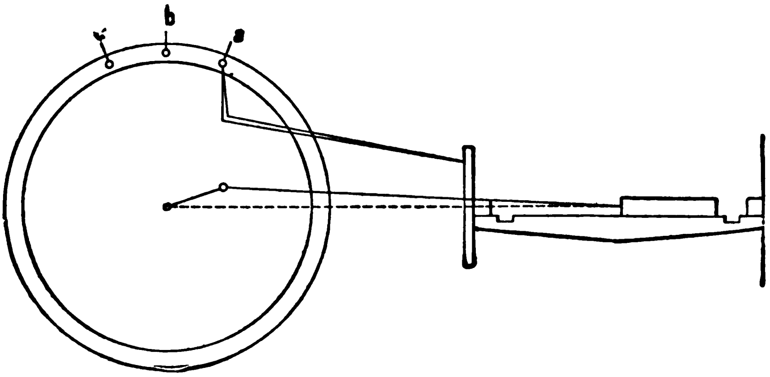


Fig. 5.

Finally turn the crank to the other center and see that the same lead is given there. If not, first go over the length of the valve-rods and eccentric-rods to ascertain that they are all right, and then, if the valve motion is properly designed, the lead will be the same. In case this does not occur, lengthen or shorten the eccentric-rod, as the case demands in order to secure equal lead.

In the designing of a link motion for locomotives the service to be rendered is to be especially considered. Valves are designed differently for high-speed express than for low-speed freight engines.

The first point to be settled is the latest point of cut-off for the engine in full gear, also the maximum valve opening for the same position of the link. Let the size of the steam port be determined according to Valve Gears, page 30. A fair average of maximum port opening for full gear on high speed engines may be taken at 1¼ times the width of the port. The point of maximum cut-off may also be placed at three-quarters of the stroke. It may be at seven-eighths of the stroke for freight locomotives. It then remains to determine the outside laps of the valve and the throw of the eccentric. The latter is equal to twice the valve opening plus twice the outside lap. To determine these dimensions draw any circle A E C F, Fig. 6, with a radius greater than the maximum port opening already determined. Lay off D C on the diameter A C, equal to the port opening at full gear, and erect D B the perpendicular to A C. Then the point B will approximately represent the position of the eccentric when the engine is on the forward center.

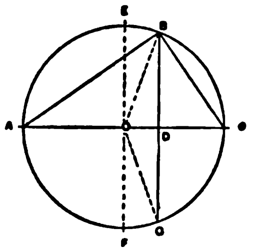


Fig. 6.

If the valve begins to open at B and closes at G, and the cut-off occurs at three-quarter stroke, then the angle B O G will be approximately three-quarters of 180°, and B O C will bear the same relation to 90°, and will be 67½°. In this case then, the distance O D, or the approximate lap of the valve, will be .62 of D C, and the whole diameter A C or the throw of the eccentric will be about 3¼ times the maximum port opening. This method will usually give decimal dimensions. They can be changed to those generally used and will serve as a guide upon which to work.

For example take a high-speed engine with a cylinder 20 inches in diameter and a piston stroke of 28 inches. It is desired to design the valve motion.

First determine the size of the steam port. This may be given an area of about one-tenth that of the piston. It will be noticed that this is somewhat smaller than the dimensions given for stationary engines on page 30 of Valve Gears.

The area of a 20-inch piston is 314.16 square inches. One-tenth of that would be 31.416 square inches. In case the port is made 19 inches long, the width will be about $1\frac{5}{8}$ inches.

If the maximum valve opening is to be $1\frac{1}{4}$ times the port opening, it will be about $2\frac{1}{32}$ in. Placing the lap at .62 of the maximum port opening it will be about $1\frac{1}{4}$ inches. Hence the total valve travel will be

$$(2.03125 + 1.25) \times 2 = 6.5625 \text{ inches.}$$

Adjusting these figures to convenient approximate dimensions we may place the port opening at 2 inches, and the lap at $1\frac{1}{8}$ inches with an eccentric throw of $6\frac{1}{4}$ inches.

Next determine the length and position of the rocker arms. When the arms are in their central positions they must stand at right angles to the valve stem and a line drawn from the lower arm to the center of the driving axle respectively. The arms should not be less than from $2\frac{1}{4}$ to $2\frac{1}{2}$ times the travel of the valves. A front elevation of a rocker is shown in Fig. 7. For the case in hand they may be made 15 inches long. The proper method of getting the set-back of the lower arm is to locate on a sheet of drawing paper the centers of the rocker shaft A and the main axle B as in Fig. 8. Draw the line A B and from its center C, with C A as a radius, draw the arc of the circle A D.

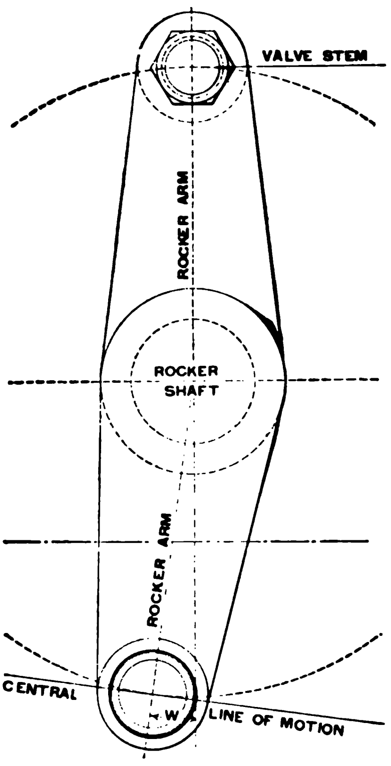


Fig. 7.

Draw the chord A E equal to the length of the lower arm of the rocker and draw the vertical line A F at right angles to A B. The distance E F will then be the set-back of the lower rocker arm.

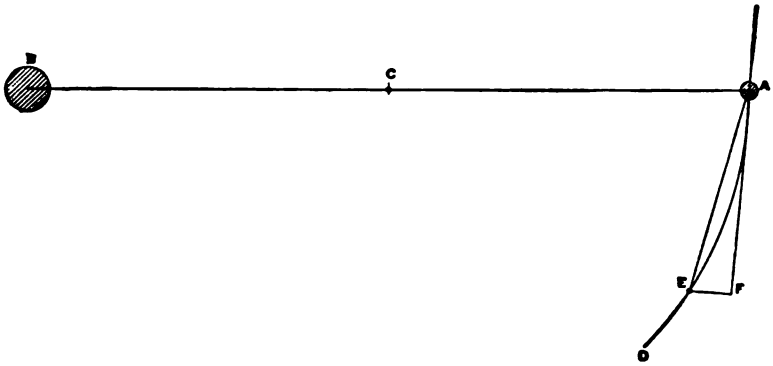


Fig. 8.

The design of the lifting shaft comes next. In this the horizontal arm should be of such a length that it can swing through the distance necessary for the raising and lowering of the link without describing too great an arc. It is well to give it a length at least 25 per cent. greater than the distance between the points of attachment of the eccentric-rods on the link. The latter may be about 2.5 times the throw of the eccentric. Thus in the case in hand the points of attachment for the eccentric rods on the link may be made 15 inches and the length of the lifting arm 18 inches. The link hanger may have any convenient length.

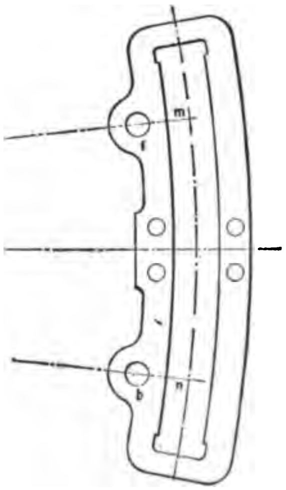


Fig. 9.

In the designing of the link the radius of the curve *m n* (Fig. 9) passing through the center of the slot, should be equal to the distance from the center of the pin at the lower end of the bottom rocker arm to the center of the main driving axle. With these dimensions fixed, it now remains to locate the position of the saddle pin and the center of the lifting shaft.

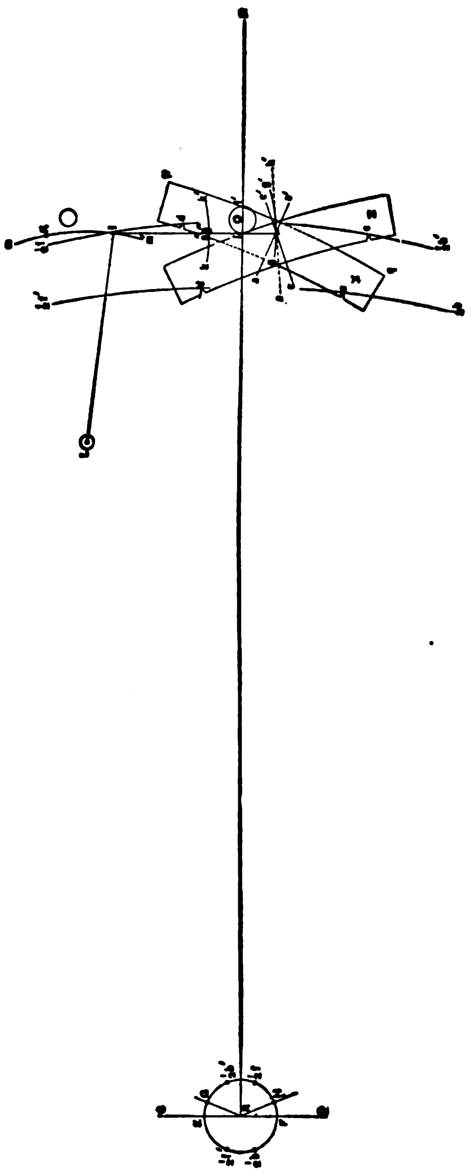


Fig. 10.

To do this accurately, the work of drawing should be done to a full size scale. To assist in this work cut a template out of tin or thin wood, as in Fig. 10, representing the link. In this the line *p q* represents the radius of curvature, and the notches at *d* and *e*, the points of attachment of the front and back eccentric-rods respectively.

Plot the center of the axle and rocker as in Fig. 10. About the center A of the axle draw a circle whose diameter is equal to the throw of the eccentric. Draw the line A B to represent the central line of motion, and then draw the line C D at right angles to it. From the points E and F lay off the arcs E G and F H equal to the lap and lead or the angular advance of the eccentric. G and H are the positions of the forward and backing eccentrics respectively when the crank is on the forward center. About the center O, which is the lower end of the rocker arm, draw the circle *l l'* with a radius equal to the lap of the valve.

The saddle pin should be so located that the point of cut-off will be equalized for half stroke cut-off. Mark the points $\frac{1}{2} f$ and $\frac{1}{2} b$ to indicate the positions of the two eccentrics at half back stroke, and $\frac{1}{2} f'$ and $\frac{1}{2} b'$ for the positions at half forward stroke respectively. From each of these points draw the arcs $\frac{1}{2} f$, $\frac{1}{2} b$, $\frac{1}{2} f'$ and $\frac{1}{2} b'$ respectively with a radius equal to the radius of the link less the distance (*f m*, Fig. 9) from the eccentric rod-pin to to the link center E. Place the template in the two midgear positions X and Z, that is with the center line passing through the points *l'* and *l* and with the points indicating the eccentric studs on the lines $\frac{1}{2} f'$, $\frac{1}{2} b$ and $\frac{1}{2} f$ and $\frac{1}{2} b'$, respectively. Draw the two other center lines *a a'* and *c c'*. On these two lines locate the points *s* and *s'* so that they shall be at equal distance from the center lines of their respective links and yet on the same horizontal straight line *h h'*. These points will then be the proper location of the saddle pin.

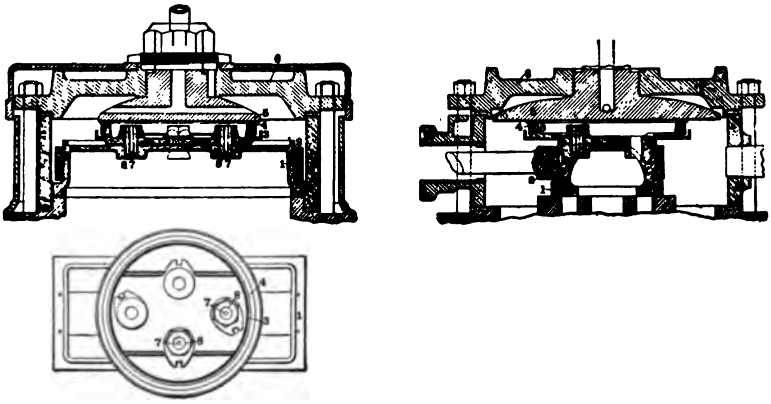


Fig. 11.

To locate the position of the lifting shaft, draw the arcs *g g'* and *k k'* with a radius equal to the length of the link hanger passing through *s s'* and *s'' s'''* respectively. The centers of these arcs I and K will be the location of the ends of the lifting shaft arms in the front and back half gears. Then, with a radius equal to the length of the lifting arm, describe the arc *m m'*. The center of this arc at L will be the proper location of the center of the lifting shaft.

The valve ordinarily used upon locomotives, is the plain slide valve, which, since the introduction of high steam pressures, is always partially balanced. In the ordinary slide valve the full steam chest pressure is exerted over the whole of the back surface of the valve. Balancing consists of a removal of a portion of this pressure and thus lowering the frictional resistance of the valve upon its seat. The percentage of this pressure that is removed or the "amount of balance" varies greatly. It runs from 45 to 90 per cent. of the total face of the valve. A fair average of good practice may be taken as about 65 per cent. In the valve shown in Fig. 11 the balance is 69 per cent. But the pinch of the packing ring on the cone adds somewhat to the pressure of the valve on its seat.

In Fig. 11 the valve 1 is of the ordinary D type driven by the yoke 2. To the back of the valve there is bolted a circular plate 3, having a cone turned thereon. On this cone there is fitted a loose ring 4 whose inner face is beveled to the same degree as the taper of the cone. The ring is cut at one point and is therefore flexible. The open space at the cut in the ring is covered by an L-shaped clip, which is placed on the outside and fastened to one end of the ring, the other end of the ring remaining free. This L-shaped clip reaches to the top of the ring on the outside and under the ring at the bottom to the taper of the cone. It thus forms joints just the same as the ring itself, making a continuous yet flexible ring. The ring is made of cast iron. It is bored smaller than the diameter required for the working position; therefore, before the steam chest cover is placed in position it sets slightly higher on the cone than it does when at work. To the under side of the steam chest cover 6, there is bolted a back plate 5, against which the ring 4, forms a steam-tight joint. Owing to the raised position of the ring when first put on, the placing of the cover and back plate forces the ring down over the cone. This expands the former to a larger diameter and it is thus held in this expanded position under tension, with a tendency to maintain the joint between itself and the wearing plate.

In order to provide for any leakage that may occur past the ring and to prevent an accumulation of pressure within the same, holes 7, are drilled through the studs, 8, into the exhaust cavity. This drains the space and accomplishes the desired result. When the balanced valve is used a relief valve is placed on the steam chest. This is a check valve opening inward and serves to prevent cinders and smoke-box gases from being sucked into the steam chest through the exhaust pipe when the throttle valve is closed and the engines running.

Another form of valve that is being extensively introduced is the piston valve, Fig. 12. In this valve the steam is admitted at the center, in the space A, and is exhausted at the ends. As the steam surrounds the valve the latter is self-balanced. It only remains to so pack the ends that the steam cannot leak by. This is done by the use of packing rings. The packing consists of seven pieces at each end numbered 1, 2, 3 and 4. Nos. 3 and 4 are the packing rings proper. They consist of the split rings, 3, and the L-shaped covering piece 4, for the split in No. 3. The rings 2 are solid and serve merely as surfaces against which the rings 3 have a bearing. The wedge ring 1 is split and can expand. The rings 3 are turned larger than the diameter of the steam chest and are sprung into position. Some small holes 5, are drilled from the steam space A to a point beneath the wedge ring 1. When the throttle valve is opened, steam enters the holes 5, and by forcing the wedge 1, out between the rings 2, it locks the packing ring 3 firmly between the ring 2 and the lip of the valve. This prevents all rattling and working loose of the rings. The valve is then practically a steam-tight plug valve.

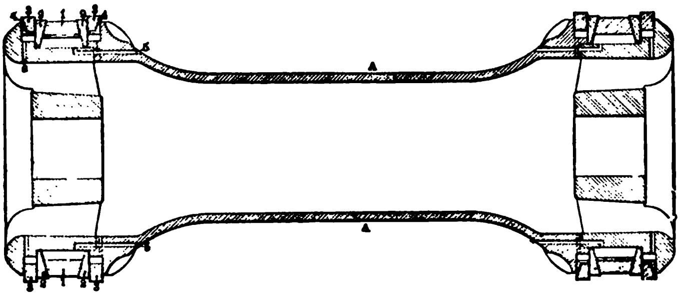


Fig. 12.

In designing such a valve care should be taken to have the edge of the valve formed by the edge of the packing as in Fig. 12. If the packing is flush with the valve and set back from the edge as in Fig. 13, the working results will be unsatisfactory.

The form of the D valve is sometimes modified and the Allan valve with an auxiliary port as described in "Valve Gears" is used.

Lap. The effect of lap on locomotives with the valve operated by the Stephenson link motion is the same as that tabulated for the ordinary slide valve on page 12 of "Valve Gears." Owing to the difficulty of getting rid of the low tension exhaust steam in the cylinders of high-speed locomotives, it has become common practice to give the valves of such engines a negative inside lap as at *a* in Fig. 14. In this the width of the valve opening is greater than the distance across the bridges of the valve seat. The result is to obtain an earlier opening of the exhaust, less compression, and less back pressure. Such negative lap is not used on freight locomotives. In general it may be stated that the higher the speed the greater the lap and the less the lead that is used.

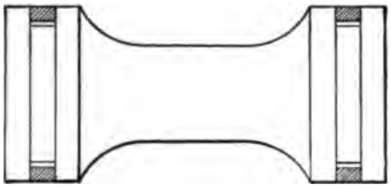


Fig. 13.

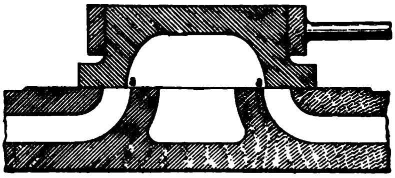


Fig. 14.

Running Gear. This consists of the wheels, axles, and boxes.

The Driving Wheels are invariably made with a cast center protected by a steel tire. The center may be of cast iron or steel. For small engines cast iron is commonly used. Until about 1896 it was universally employed. For heavy engines with large cylinders, where a saving of weight is important, cast steel is now used. A side elevation of such a wheel is shown in Fig. 15. The usual method of fastening the tire to the center is to bore it out a trifle smaller than the diameter to which the center is turned, then expand it by heating and, after slipping it over the center allow it to contract by cooling. The shrinkage used by railroads is $\frac{1}{80}$ inch per foot of diameter. In the case of large wheels of 66 inches or more in diameter, the tires are sometimes given an additional fastening with Mansell retaining rings. These are shown in Fig. 15, and in section in Fig. 16. The rings consist of the plates A A, Fig. 16, with lips fitting into the grooves of the tire and bolted to the center.

The American Railway Master Mechanics' Association have adopted a standard form of wheel tread that is shown in section with the dimensions in Fig. 16.

Axles are almost universally made of steel for driving wheels, truck wheels and tenders. The driving axles should be turned off the same diameter from the ends back to a point inside the eccentric seats. There should be no shoulder upon them, and the diameter at the center may be a little less than at the ends. The wheels are fastened on, first by pressing on with a pressure of from forty-five to sixty tons, dependent upon the size of the axle, and then by keying with one or two keys. These keys must be very accurately fitted and when two are used may be spaced 120 degrees apart.

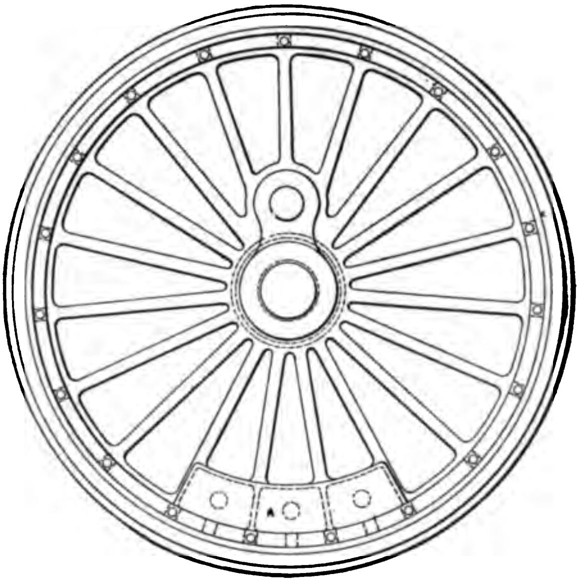


Fig. 15.

Counter-balancing. The purpose of adding counter-balance weights (A Fig. 15) to the driving-wheels of locomotives is to prevent or minimize the stresses and vibrations caused by the momentum or inertia of the moving parts attached directly or indirectly to them. These are of two kinds, revolving parts and reciprocating parts. The revolving parts can be counter-balanced by weights attached to the wheel to which they belong. The reciprocating weights can only be balanced in one direction by adding weights to the driving wheels, as all weights added after the revolving parts are balanced, overbalance the wheel vertically, exactly to the same extent that they tend to balance the reciprocating parts horizontally. This overbalance exerts a pressure upon the rail directly proportional to its weight and to the square of its velocity. At high speeds this pressure, which is added to the weight of the driver on the rail, may become great enough to injure track and bridges.

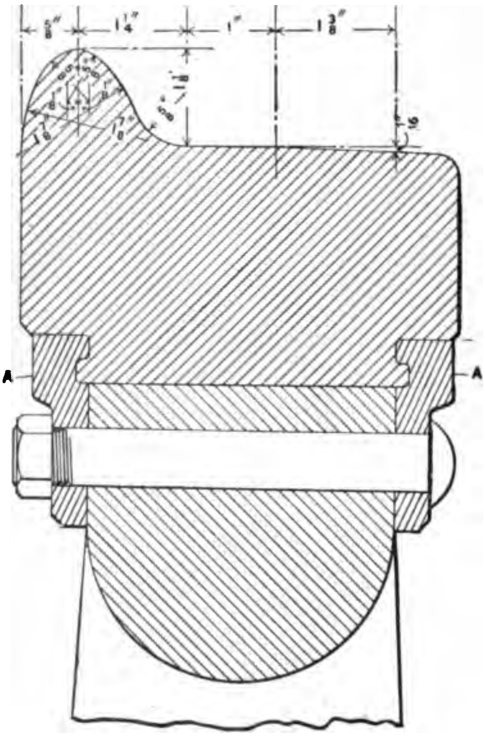


Fig. 16.

The following fundamental principles are, therefore, laid down to be followed in counter-balancing.

First: The weight of the reciprocating parts, that is left unbalanced, should be as great as possible, consistent with a good riding and a smooth working engine.

Second: The unbalanced weight of the reciprocating parts, of all engines for similar service, should be proportional to the total weight of the engine in working order.

Third: The total pressure of the wheel upon the rail at maximum speed, when the counter-balance is down, must not exceed an amount dependent upon the construction of bridges, weight of rail, etc., and, when the counter-balance is up, the centrifugal force must never be sufficient to lift the wheel from the rail.

In designing new locomotives the proper counter-balance weight should be calculated and cast into the wheel centers as follows:

Place the center of gravity of the counter weight opposite the crank-pin as far from the center of the wheel as possible, and have it come as near the plane in which the rods move as proper clearance will allow. To obtain the weight of the reciprocating parts and detachable revolving parts, proceed as follows:

Reciprocating Parts. Take the sum of the weights of the piston complete, with packing rings, piston rod, crosshead complete and the weight of the front end of the connecting-rod complete.

To get the weight of the rods support them on the centers and take the weight there imposed.

Revolving Parts. Weigh the back end of the connecting-rod and each end of each side-rod complete. The sum of the weights so found, which are attached to each crank-pin, is the revolving weight for that pin.

The rules for the counter-balancing of locomotive driving wheels are as follows:

First. *Divide the total weight of the engine by 400; subtract the quotient from the weight of the reciprocating parts on one side, including the front end of the main rod.*

Second. *Distribute the remainder equally among all driving wheels on one side, adding to it the sum of the weights of the revolving parts for each wheel on that side. The sum for each wheel, if placed at a distance from the driving wheel center equal to the length of the crank, or a proportionally less weight if at a greater distance, will be the counter-balance required.*

The shop method of adjusting the counter-balance is as follows: —

Place the axle with the journals upon straight edges. Level the straight edges by means of adjusting screws. Turn the wheels until the center of one crank-pin is above and exactly in a vertical line drawn through the center of the axle. Then hang weights on the opposite pin until their sum equals the exact weight of all the detached revolving parts on this wheel, plus the proportion of the reciprocating weights determined by the rules given above. Increase or decrease the counter-balance opposite the crank-pin until it exactly balances the weight thus applied. Repeat this process for the opposite wheel.

Increased weight of counter-balance can be obtained, when necessary, by boring out cast iron and substituting lead.

In order that a wheel shall never leave the rail, 40 times the portion of the weight of the reciprocating parts added to each wheel, must not exceed its static pressure on the rail. To insure safety it should not exceed 75 per cent. of such pressure. Nor should this amount, when added to the static wheel pressure, exceed the safe maximum pressure allowed on track and bridges.

The reciprocating parts should be as light as possible. The distance from center to center of cylinder should be as small as possible. Locomotives with rods disconnected and removed should not be hauled at high rates of speed.

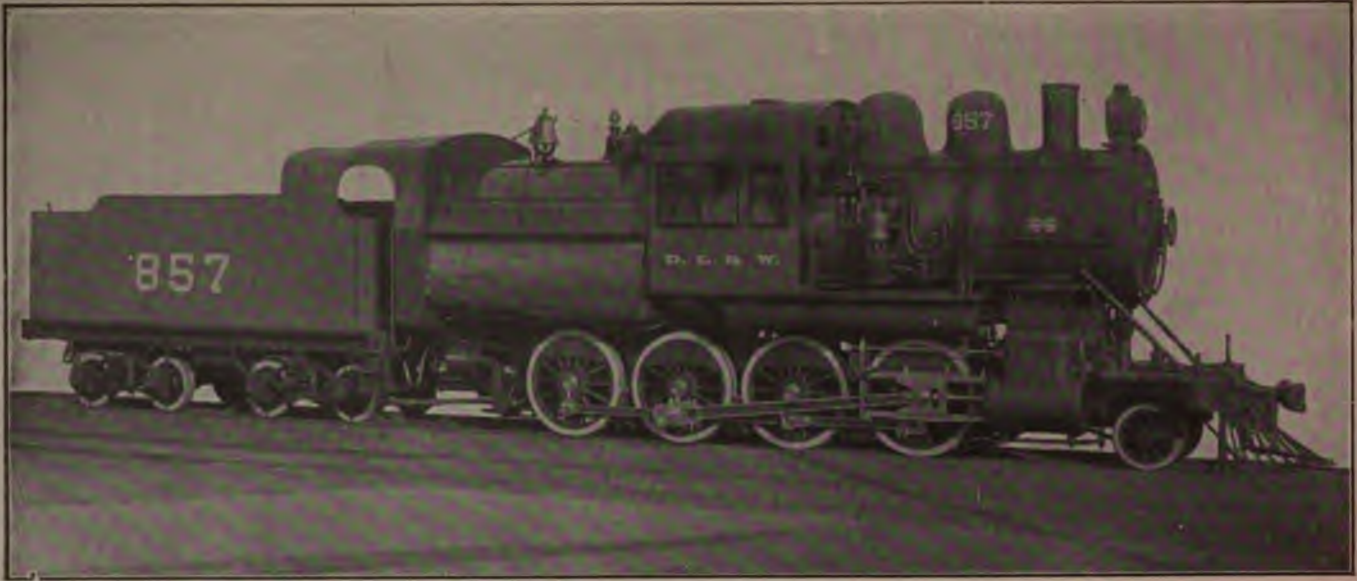
ILLUSTRATIVE EXAMPLES.

An eight-wheeled locomotive weighing 108,000 pounds has 72,000 pounds on the driving wheels. The weight of the reciprocating parts on one side of the engine, including the front end of the connecting-rod is 630 pounds. The stroke of the piston is 24 inches. The diameter of the driving wheels is 60 inches.

1. What weight of reciprocating parts should be counterbalanced? *Ans.* 360 pounds.

2. What weight must be added to each driving wheel if the center of gravity of the counter-balance thus added is 20 inches from the center of the wheel? *Ans.* 108 pounds.

3. At a speed of 60 miles per hour, what increase, over the static load, will the counter-balance given in example 2 put upon the track, due to its centrifugal force? *Ans.* 6,700 pounds.



Freight Engine, 2-8-0 Type, Built at the Schenectady Works. American Locomotive Company.

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4. What is the maximum weight of the reciprocating parts of this engine that can be counter-balanced with safety.

Ans. All.

Trucks. There are two types of trucks used under the front end of locomotives: the two-wheeled or pony truck and the four-wheeled.

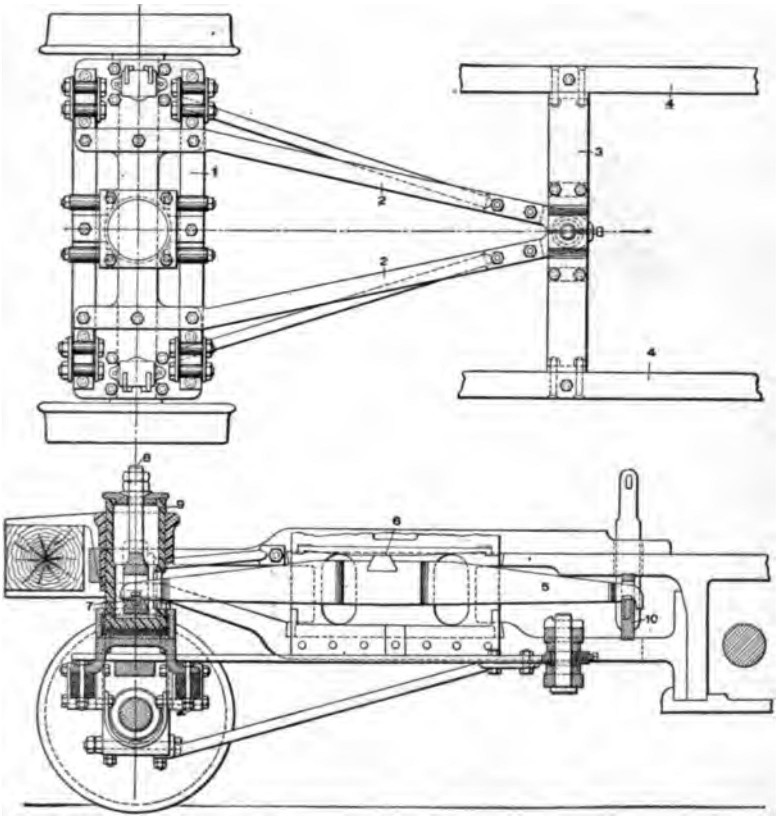

Fig. 17.

The two-wheeled truck is shown in Fig. 17. The essential elements of the pony truck are the frame 1, which carries the weight at the front end of the engine, and the radius bars 2. The latter are pivoted to a cross bar 3, that is rigidly bolted to the engine frames 4.

It is evident that if the truck were to be merely pivoted midway between the wheels, with no other fastening, there would be nothing to prevent it from swinging around and becoming derailed as soon as there was any inequality in the resistance to the advancement of the wheels. In order to prevent this the truck is steadied by radius bars pivoted to the frame and a side play is allowed at the center plate.

In order to hold the truck and, at the same time, prevent excessive flange wear, it is necessary that the length of the radius bar measured from the axle center to its pivot should be carefully proportioned.

The formula used for this purpose is as follows:

$$X = \frac{D R + D^2}{R + 2D}$$

in which

R = Length of rigid wheel base.
D = Distance of front flanged driver axle to center of truck.
X = Length of radius bar.

ILLUSTRATIVE EXAMPLES.

What should be the length of the radius bar in a locomotive having all drivers flanged, a rigid wheel base 14 feet long, and 7 feet 6 inches from the front driver to the truck center?

Ans. 5 ft. 6.72 inches.

With the pony truck, the weight is usually placed upon it by means of an equalizing lever 5. This equalizing lever has a fulcrum at 6 beneath the cylinders where the weight is applied. It rests at 10 upon a cross-bar that is carried by the driving wheel springs. At the truck end the equalizer is carried by a pin 8 whose nut rests upon a cap carried by the sleeve 9 that is supported by the center-plate. The latter is held by springs swung in hangers. The details of these trucks vary with the builder but they follow, in general outline, that given. The proportioning of the weights on the truck and driving wheels depends upon the relative lengths of the distances from 6 to 7 and 6 to 10. The diameter of the wheels of a pony truck varies with the engine. The average diameter is from 28 to 30 inches.

The four-wheeled or bogie truck is shown in Fig. 18. This truck is of an exceedingly simple construction. It consists of a rectangular frame A carrying a center-plate B. The frame is supported by two semi-elliptic springs C suspended from the equalizers D which rest directly upon the axle boxes E. The journals are inside the wheels which vary in diameter from 28 to 36 inches. The truck serves as a guide to carry the front end of the engine which is pivoted on the center-plate.

Types of Locomotives. The variations in the construction of locomotives are almost numberless owing to the differences in the services for which they are intended. These variations may, however, be classified according to the arrangements of the wheel bases.

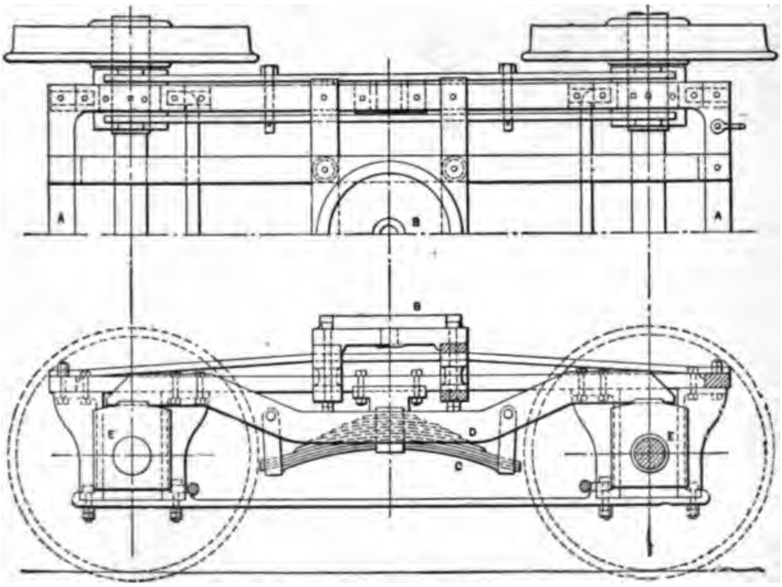

Fig. 18.

Four-Wheeled Switching. This is a type of engine that is extensively used where the service is comparatively light or where there is a limit to the length of the engine that can be used. Such an engine is shown in outline in Fig. 19. It is carried on two pairs of driving wheels and may or may not be provided with a tender for coal and water. In Fig. 19, an engine is shown in which the water is carried in a saddle-tank on top of the boiler Coal is carried in a small bunker at the back of the cab. Owing to their short wheel base these engines are not adapted to run at even moderately high speeds. Slight inequalities of the track cause them to teeter, which, if intensified, will put such a stress upon the springs as to break them.

Eight-Wheeled Locomotive. The type of engine, shown in Fig. 20, was for many years the standard used upon all the roads of the United States for both passenger and freight service. It is known, therefore, as the American type of locomotive. Like the switching engine of Fig. 19, it has four driving wheels, but has, in addition, a four-wheeled or bogie truck under the front end

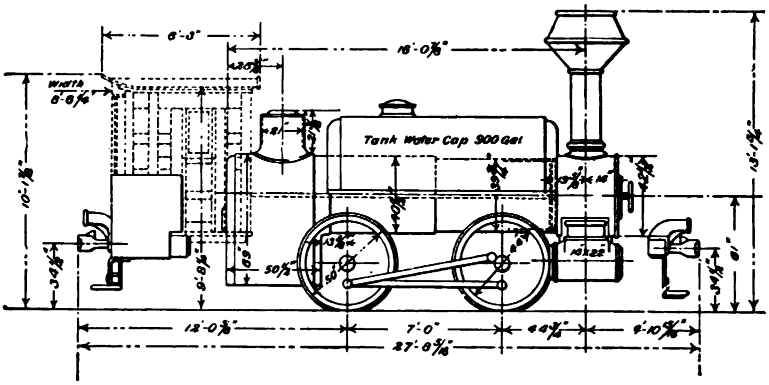

Fig. 19.

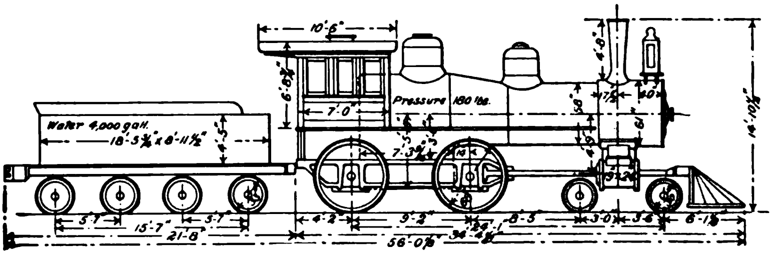

Fig. 20.

The sizes of the cylinders vary with the service in which the engine is to be engaged. They may be said to run from a diameter of from 16 to 20 inches with a stroke of 24 or 26 inches. These engines are invariably supplied with a tender to carry coal and water. Owing to their short rigid wheel base and the flexibility given them by the bogie truck they are especially adapted for high speed express passenger service. They have, however, been supplanted by other types for freight work.

Forney Locomotive. This engine, Fig. 21, is named after its original designer, Mr. M. N. Forney. In all essential particulars it is an eight-wheeled engine. The bogie truck is merely placed at the back instead of the front. The four driving wheels carry the weight of the engine as in Fig. 19. The frames are extended back of the cab and the water-tank and coal-box are placed upon them. The bogie truck carries the weight of the coal and water. These engines were originally designed for suburban service where trains are run at frequent intervals and it was desired to avoid the delays due to the turning of the engine at the end of each trip. They have been extensively used for such purposes. They were also the standard type of engine used on all elevated railroads in New York and Chicago before the adoption of electricity as a motive power.

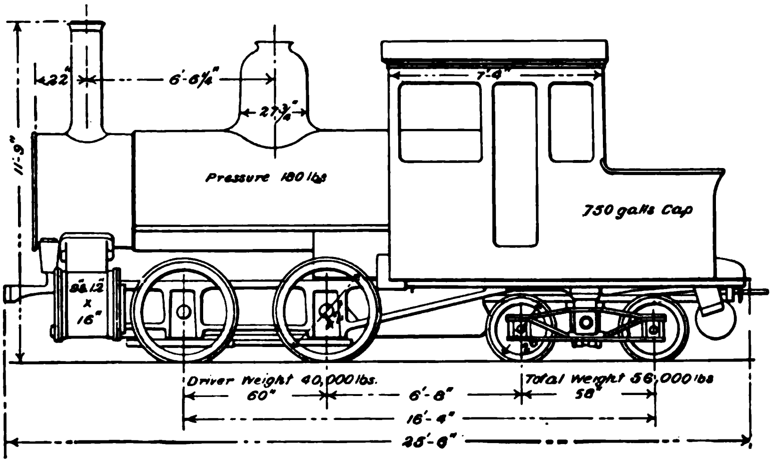

Fig. 21.

Columbia. Another modification of the eight-wheeled locomotive is found in the Columbia. This engine is shown in Fig. 22 and is interesting merely because it was the predecessor of the Atlantic type. Only one has been built. It has two pairs of driving wheels with a pony truck under the front end and a pair of trailing wheels to carry the fire-box. The back pair of driving wheels are the main drivers. The fire-box is back of the rear pair of drivers. The object of this form of construction was to obtain a wide and deep fire-box. The width is only limited by the side clearances of the roadway and the depth may be sufficient for soft coal or coke.

Atlantic. This type, Fig. 23, is a modification of the Columbia. The difference lies in the substitution of a four-wheeled for a bogie truck at the front end. Its name is derived from the fact that it was first used on the line between Camden and Atlantic City, N. J. Both the Columbia and Atlantic types are designed for very high speed passenger service. The short rigid wheel base and flexibility at the front and back contribute to this end.

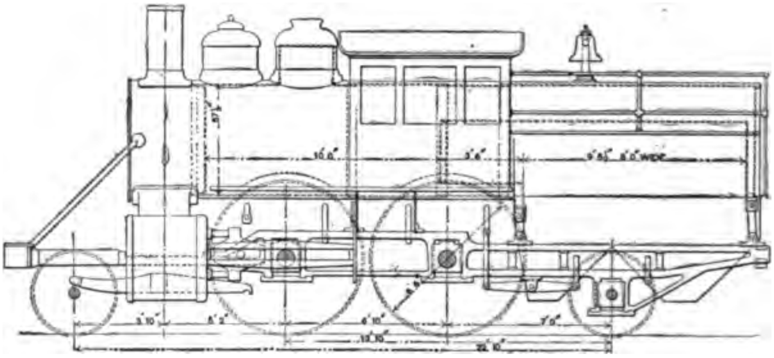

Fig. 22.

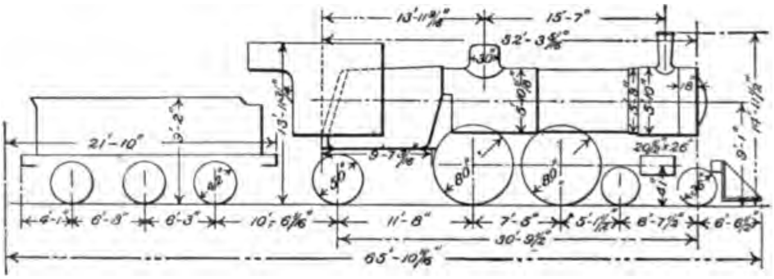

Fig. 23.

Single Driver locomotives are seldom used in the United States except as special engines, such as superintendents' and roadmasters' locomotives. A few have been built for express passenger service like that shown in Fig. 24. They have, however, been supplanted by locomotives of the Atlantic type.

Six-Wheeled Switcher. The simplest form of locomotive having three pairs of driving wheels is found in the six-wheeled switching locomotive, Fig. 25. These engines possess an advantage over the four-wheeled type, in that they are more powerful. The engine is carried on the six driving wheels. It is provided with a tender. The back of the latter is sloped down to enable the engineer to see the track close to the engine at the rear.

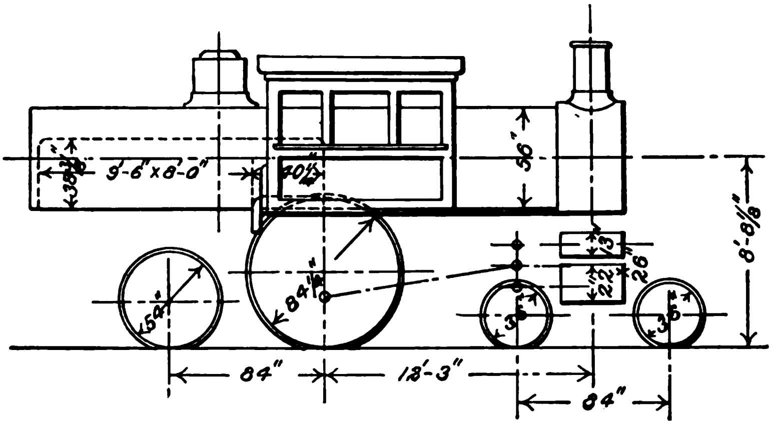

Fig. 24.

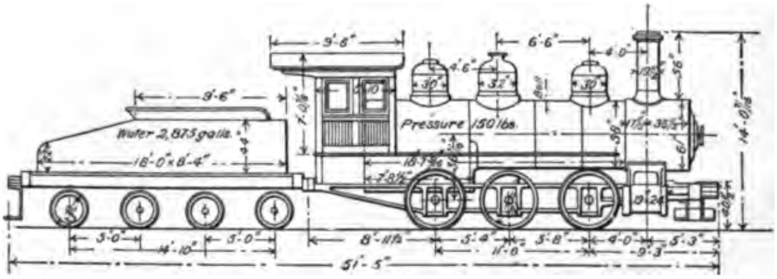

Fig. 25.

Mogul. The mogul type of locomotive, Fig. 26, has three pairs of driving wheels and a pony truck ahead. Its name was originally a shop nickname indicative of large size. It was at first intended for freight service, but it is frequently used for the hauling of heavy passenger trains. The object of the design is to obtain a greater tractive force on the driving wheels than is possible on four, as is the case of the American type of locomotive. In mogul locomotives the middle pair of wheels are the main drivers and the parallel rods run forward and back to the others.

Ten-Wheeled Locomotive. This engine, Fig. 27, as its name indicates, is carried on ten wheels. Six of them are driving wheels and four are in a truck forward, similar to that shown in Fig. 18. This type of engine was designed for the hauling of heavy trains in passenger service. It has the same advantage as the mogul over the American type in increased adhesion, while it possesses an additional advantage over the mogul in that the boiler may be made larger and the extra weight carried on the additional pair of wheels of the truck. As passenger service requires a higher evaporative power than freight, the increase in the size of the boiler is necessary. As in the mogul the middle pair are the main drivers.

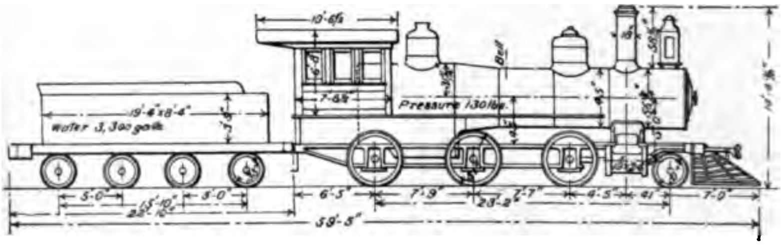

Fig. 26.

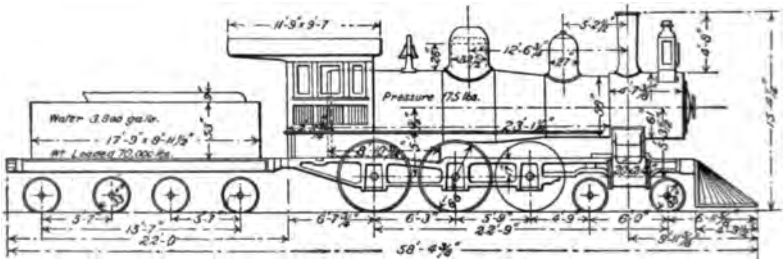

Fig. 27.

Consolidation. This type of locomotive, Fig. 28, is used exclusively for freight service. It is carried on ten wheels, of which four pair are drivers. The same reason that led to the adoption of the mogul locomotive in the place of the American type, (the necessity for greater tractive power) also led to the addition of a fourth pair of driving wheels to the mogul and produced the consolidation. In these engines the second pair of drivers, counting from the front, are the main wheels. The increased number of wheels makes an increase of weight possible, and with it a larger boiler and cylinders.

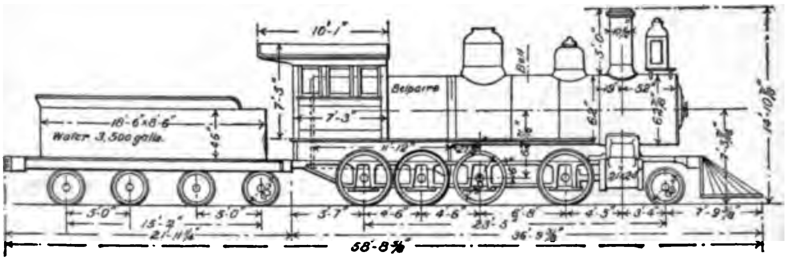

Fig. 28.

Decapod. This engine, Fig. 29, like the consolidation and as its name implies, is carried on ten wheels. All of these wheels are drivers. It is not built for ordinary road service, but is used as a pusher on hills where heavy grades are to be overcome.

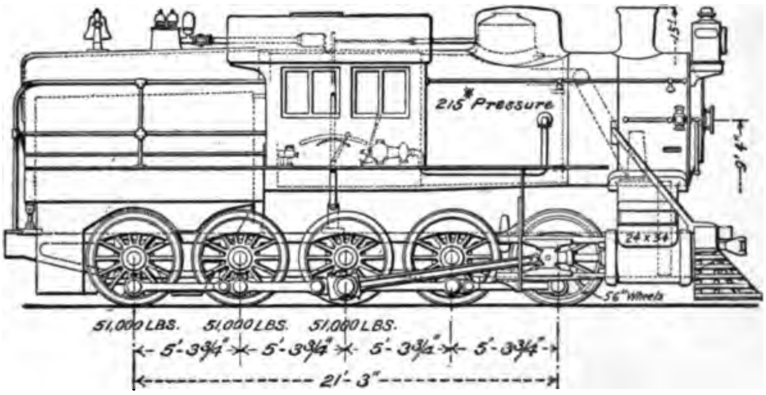

Fig. 29.

The Mastodon locomotive, (shown in Fig. 30) bears the same relationship to the consolidation engine that the ten-wheeler does to the mogul. A four-wheeled truck has been substituted for the pony. This substitution makes a larger boiler and cylinders possible, thereby increasing the power of the engine. They are used exclusively for heavy freight service.

Compound Locomotives. The compound locomotive is an engine in which the steam is admitted to one cylinder, called the high-pressure, where it partially expands in doing its work. It is then exhausted into the steam chest of a larger cylinder, called the low-pressure, whence it is admitted to that cylinder to complete its expansion. The chief advantage of the compound locomotive lies in the saving effected in cylinder condensation. It will be borne in mind that the back pressure of the high-pressure cylinder is approximately the working pressure of the low-pressure cylinder.

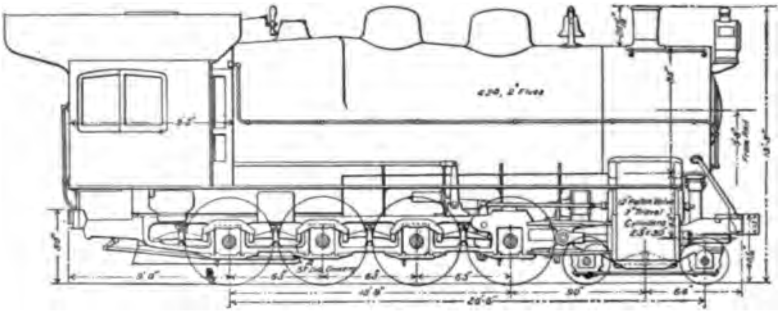

Fig. 30.

This principle has been applied to locomotive work in three ways: by the use of two, three and four cylinders.

In the two-cylinder compound there is one cylinder on each side of the locomotive. The steam passes from the high-pressure cylinder through the smoke-box and across the engine to the low-pressure cylinder.

In the three-cylinder engine, there is one high-pressure cylinder on each side of the engine. The steam from these cylinders is exhausted into the steam chest of one large low-pressure cylinder that is located beneath the smoke-box.

In the four-cylinder compound locomotives, as built in this country, there is a high and low-pressure cylinder on each side of the engine. These work in pairs independently of each other.

With the two and three-cylinder engines there are two exhausts into the stack at each revolution of the driving wheels: with the four-cylinder engine, there are four.

The following are the principal types of compound locomotives:

Richmond Compound. This compound locomotive is of the two-cylinder type. That is to say it has two cylinders similar to the simple locomotive. One is a small or high-pressure cylinder that is placed on the left-hand side of the engine and the other is a large or low-pressure cylinder which is on the right-hand side The general arrangement of the cylinders and their connections is shown in Fig. 31, which is a diagram of the front elevation of the smoke-box and cylinders. In this engraving the course of the steam from the boiler to the exhaust nozzle is indicated by the arrows. From these it will be seen that the steam entering the tee head from the dry pipe passes down through the main steam

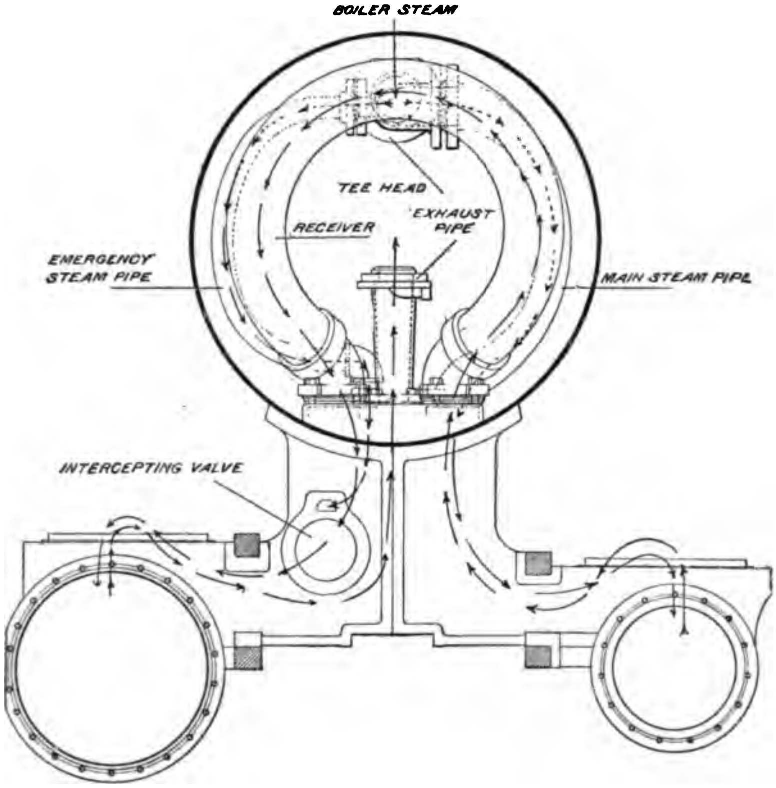

Fig. 31.

pipe on the left-hand side of the engine to the high-pressure cylinder. Here it does work, is partially expanded and is exhausted into the receiver. The receiver is a large pipe crossing the smoke-box in the form of an arch and carrying the exhaust from the high-pressure cylinder to the intercepting valve. From the intercepting valve it goes to the steam chest of the low-pressure cylinder, where its expansion is completed and from which it escapes into the exhaust pipe and thence into the stack and atmosphere.

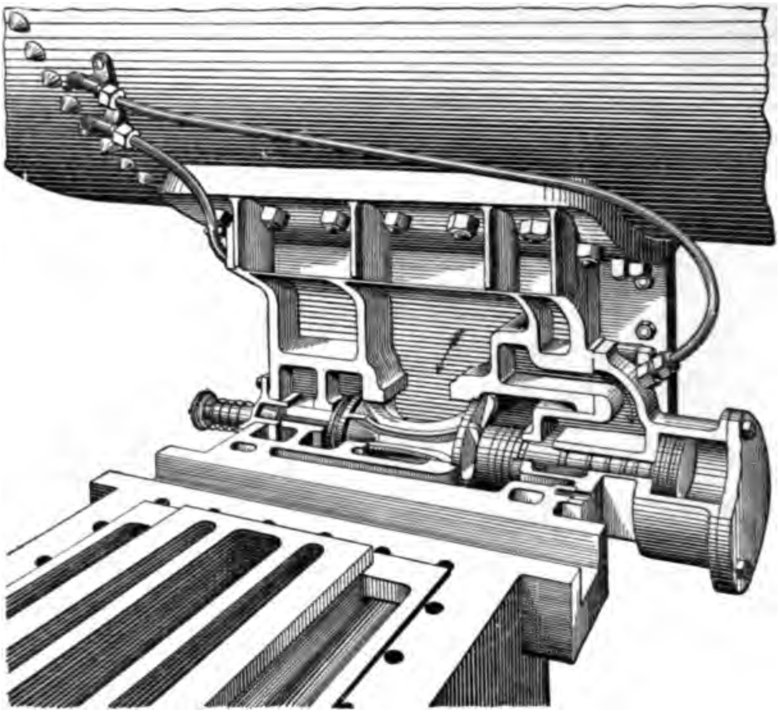

Fig. 32.

A perspective view of the front of such an engine is given in Fig. 32, in which a portion of the cylinder casting is cut away showing the intercepting valve in position.

The peculiarity of the Richmond compound locomotive is to be found in the construction of its intercepting valve.

It is evident that should a compound locomotive stop with the crank of the high-pressure cylinder on the dead center, it would be necessary to admit live steam to the low-pressure cylinder in order to start the engine. For, if the start were to depend on the compound working of the engine, it could not take place until an exhaust had been delivered by the high-pressure cylinder into the receiver.

It is the function of the intercepting valve to admit live steam to the low-pressure cylinder whenever the engine is to be started and then to automatically cut off (intercept) that flow of steam when the exhaust of the high-pressure cylinder has raised the pressure in the receiver leading to the low-pressure cylinder, sufficiently to enable it to deliver steam to the latter so that it can do its proper share of the work.

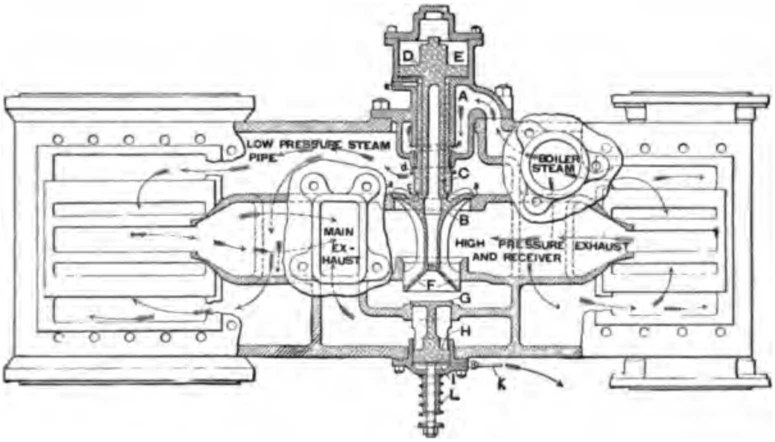

Fig. 33.

The operation and construction of the Richmond intercepting valve is shown in Figs. 33 to 37. In all of these figures similar parts are indicated by similar letters.

In Fig. 33 the intercepting valve is shown in the position in which it stands immediately after the opening of the throttle valve for the starting of the engine. When in this position steam at boiler pressure enters the cylinder casting at the point indicated and flows to the high-pressure steam chest and cylinder as indicated by the arrows. It also enters the space A which is always filled with steam at boiler pressure when the engine is at work.

On the stem of the main intercepting valve B, there is a loose sleeve which is turned with a shoulder *d*. The live steam acting on this shoulder pushes the sleeve out and forces the main valve B against its seat *a a*. This closes the only means of communication between the high-pressure exhaust passage and receiver and low-pressure steam pipe. When in this position the live steam from A is free to flow out through the opening around the sleeve C, into the low-pressure steam pipe and thence into the low-pressure steam chest. Live steam is thus admitted to both cylinders and the engine will start like any simple engine.

If, however, the engine should not start, it would take but a very short time for full boiler pressure to accumulate in the low-pressure steam pipe and cylinder, even though it might, at first, be greatly wire-drawn by passing through the space about the sleeve C. As the low-pressure cylinder is much larger than the high, an equality of pressure in the two cylinders would result in the exertion of very unequal amounts of power on the two sides of the engine and possibly a straining of the fastenings on the low-pressure side.

In order to obviate this difficulty the space at the end of the sleeve C is opened to the atmosphere so that no steam leaking past the sleeve can accumulate and create a pressure there. Live steam, however, does have free access to the end *c* which presents a larger area to the same than the shoulder *d*. The end *c* and the shoulder *d* are so proportioned that, when the desired working pressure has been reached in the receiver, the pressure acting on the large end *c* will push the sleeve back into the case, as shown in Fig. 34. When in this position the flow of steam from the boiler into the low-pressure steam pipe is cut off, and an accumulation of an excess of pressure therein avoided. If the pressure in the low-pressure steam pipe is lowered for any reason the sleeve again moves forward and permits of the passage of more live steam.

After the engine has started the steam from the high-pressure cylinder is exhausted into the receiver, and a pressure is therein accumulated beneath the valve B. As soon as this pressure reaches a point slightly in excess of that existing in the low-pressure steam pipe, it forces the valve B into the position shown in Fig. 35. In taking this position the sleeve C is carried with it and the shoulder *d* brought to a bearing as a valve against its seat. The flow of steam from the boiler to the low-pressure cylinder is thus cut off; the exhaust from the high-pressure cylinder is free to pass directly to the low-pressure steam chest and the engine works as a compound.

As the high-pressure cylinder of a compound locomotive is slightly larger than that of a simple engine of the same capacity, it follows that it is more powerful when working as a simple engine. In order to take advantage of this fact both in the starting of heavy loads and in the surmounting of steep grades, provision has been made for working the locomotive as a simple engine and preventing it from automatically changing into a compound.

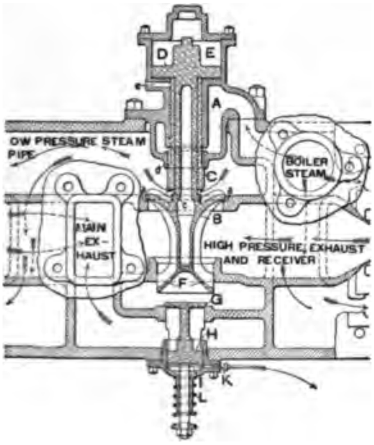

Fig. 34.

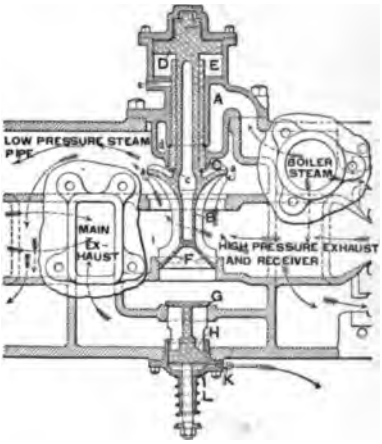

Fig. 35.

This is done by means of a valve G. When this valve is opened as in Fig. 36, it allows a free passage of the exhaust steam of the high-pressure cylinder through the receiver and out at the main exhaust. Under these conditions there is no accumulation of pressure in the receiver and the valve B will remain closed. In the meantime an excess of pressure in the low-pressure steam pipe is prevented by the movement of the sleeve C, as shown in Fig. 37.

The emergency exhaust valve G is opened by admitting steam into the space I, back of the piston H, through the pipe K that leads back to the cab where it is provided with a valve. When the supply of steam to this pipe is shut off the spring L draws the valve G against its seat, where it is held by the accumulating pressure in the receiver, and the engine automatically changes to compound working as already described.

Owing to the restricted passage about the emergency valve G, the locomotive cannot be worked as a simple engine at speeds of more than six or seven miles an hour. At this speed the exhaust from the high-pressure cylinder is so badly choked and the back pressure made so excessive that no increase of speed is possible. This prevents the engineman from working the engine simple with the excessive use of steam that that method involves.

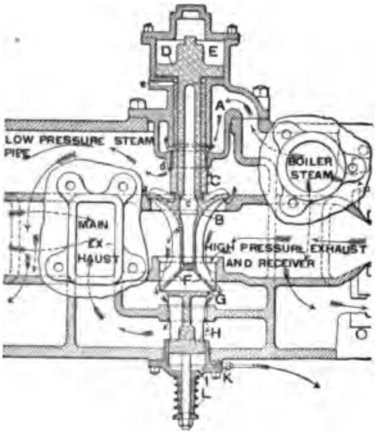

Fig. 36.

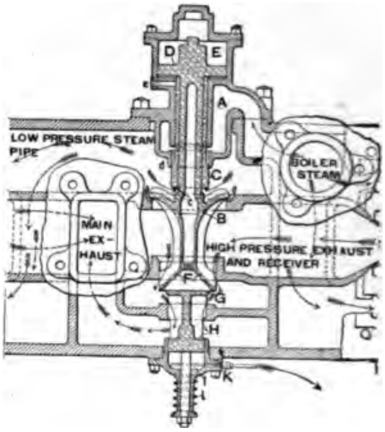

Fig. 37.

The piston D attached to the stem of the main valve and working in the dashpot E is merely to regulate the movement of the valve B and prevent it from slamming.

One of the troubles experienced with the compound engine was that, when the engine was running with the steam shut off, large quantities of air were drawn in at the relief valves on the steam chest and forced out at the exhaust pipe, creating a draft that fanned the fire when the engine was drifting, causing an excessive waste of steam and coal.

A device has been adopted on the Richmond compound, known as a by-pass valve, that overcomes this difficulty and

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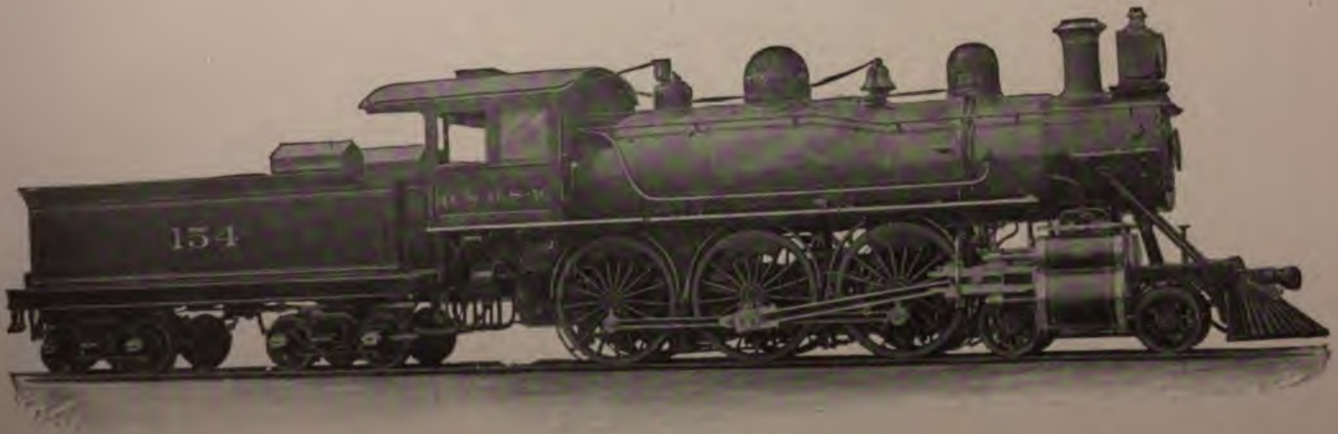


COMPOUND 10-WHEEL LOCOMOTIVE, BALDWIN LOCOMOTIVE WORKS—Total Weight of Engine, 76 Tons entirely prevents this pumping of air. It consists of a small cylinder cast on the side of the main one and having ports *a a a a* connecting it with the main steam ports and the two induction ports. In this cylinder there are fitted the two pistons *b b* that are provided with packing rings and arranged to act as valves on the seats *c c*, Figs. 38 and 39.

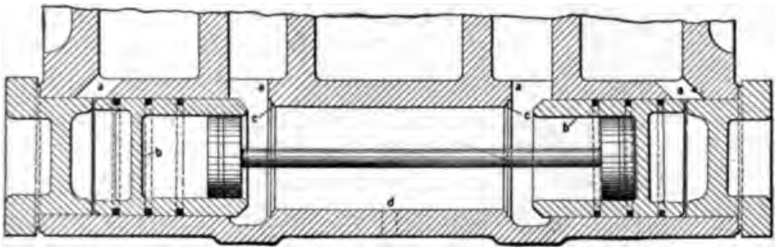


Fig. 38.

Fig. 38 shows the position of the valve when running with steam shut off. The reduction in the steam chest pressure causes the valves *b b* to move to the ends of the chambers, thus opening communication between the cylinder steam ports. When the throttle is opened these valves move to the position shown in Fig. 39 and close the steam port openings. It will be seen, too, that

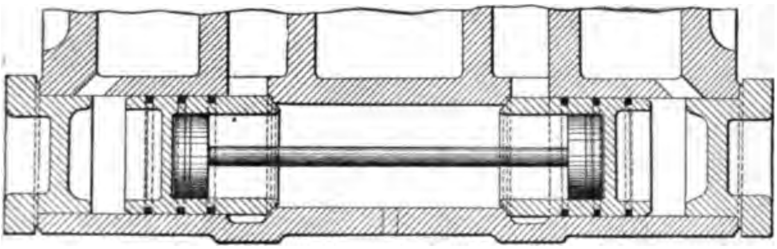


Fig. 39.

the chambers are in direct communication with the atmosphere through the vent *d*.

The effect of this adjustment of the valves is very evident. When the throttle is closed there is a free communication between the two ends of the cylinder and the atmosphere. The air contained in the former is merely churned back and forth and none is forced out at the stack. This makes it possible to run down hill with the throttle closed and avoid all fanning of the fire.

Another trouble at one time experienced with the two-cylinder compound locomotive was the inability to get rid of the exhaust steam from the low-pressure cylinders with sufficient freedom to enable the engine to run at high speeds. This difficulty has been overcome in the case of the Richmond locomotive by the use of a valve having an auxiliary port similar to that used in the Allan valve.

The time when the opening for the exhaust needs to be most efficient is at the beginning of the exhaust period. It is evident that when the exhaust opening becomes equal to the area of the exhaust nozzle a further increase in the area of the exhaust port opening will not assist in getting the steam out of the cylinder. With the increase in piston speed a certain velocity is reached, after which the back pressure during the return stroke of the piston does not decrease, and for this reason an increase of the area of the exhaust opening after the beginning of the return stroke is of very little value. The pressure at the end of the stroke should therefore be decreased in order to secure a minimum back pressure throughout the stroke. The valve under consideration was designed to secure a more rapid exhaust opening, and is termed "double ported," to distinguish it from the Allen valve. The valve port is used as an exhaust as well as an admission passage. The use of this device on compound locomotives gives low back pressure at high speeds without necessitating the use of large valves.

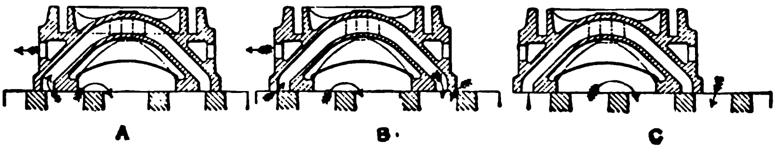

A B C

Fig. 40.

The various positions of the valve are illustrated by Fig. 40. From A it appears that the auxiliary port acts as an exhaust port only during the first portion of the exhaust period. Then when the main exhaust passage becomes sufficiently open, the passage is closed to the exhaust and acts as the regular Allan port for the admission of steam, as in B. At the limit of its travel the port is closed to both admission and exhaust as in C.

The two-cylinder compound locomotive, as thus developed, is thoroughly efficient for both freight and passenger service, and will effect a saving in fuel of from 20 to 25 per cent. according to the service in which it is run.

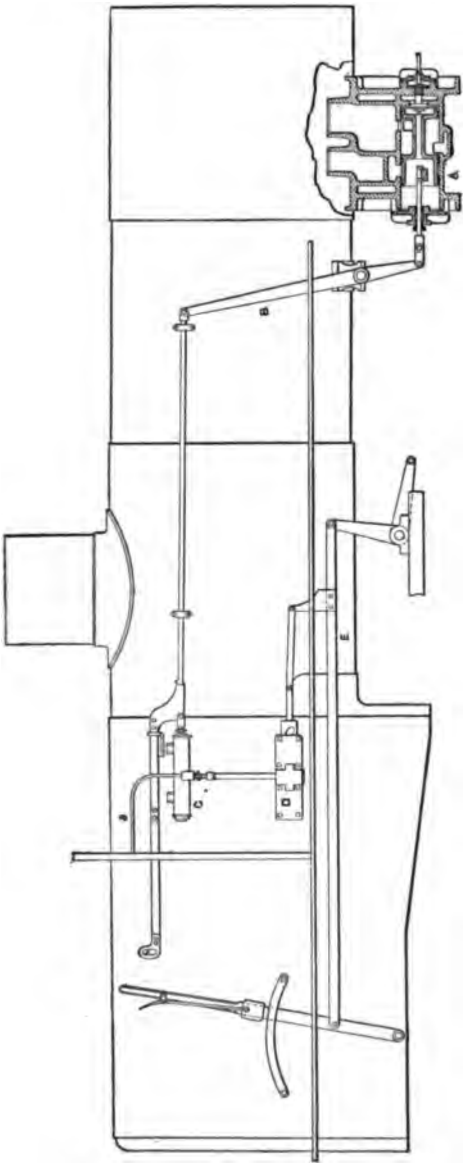


Fig. 41.

The Pittsburg Compound Locomotive. This locomotive is also of the two-cylinder type. It differs from the preceding in the fact that it is not automatic in its action of changing from single expansion to compound working. The parts consist of an intercepting valve A, Fig. 41; the valve of which is connected to one arm of the lever B. This lever is moved to and fro by a piston in the small cylinder C. The steam admission to the cylinder is controlled by a valve D, operated by a connection to the reach rod E.

When the reversing lever is in the full gear notch and the reach-rod is forward, steam is admitted back of the piston in C, and the piston F of the intercepting valve is thrown back to the position shown in Fig. 42. At the right of the intercepting valve there is a reducing valve through which steam is admitted to the receiver. This valve is so adjusted that the proper pressure is admitted to the receiver for the working of the low pressure cylinder.

When the valve is in this position the exhaust from the high-pressure cylinder passes around the body of the piston of the intercepting valve and not at G, which is the exhaust for the high-pressure cylinder.

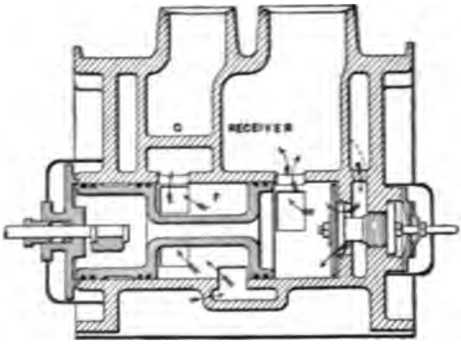


Fig. 42.

As long as the reverse lever remains in the full forward gear the engine will continue to work as a simple engine. When the lever is drawn back so as to shorten the period of steam admission, steam is exhausted from the back end and admitted to the front end of the cylinder C, Fig. 41. The piston of the intercepting valve is then moved forward to the positions shown in Figs. 41 and 43. When in these positions the engine will work as a compound. The piston F is against the reducing valve and prevents it from opening, so that no steam is admitted from the boiler into the receiver. The high-pressure exhaust is prevented from escaping through the exhaust passage G, but is led into the receiver as indicated by the arrows in Fig. 43.

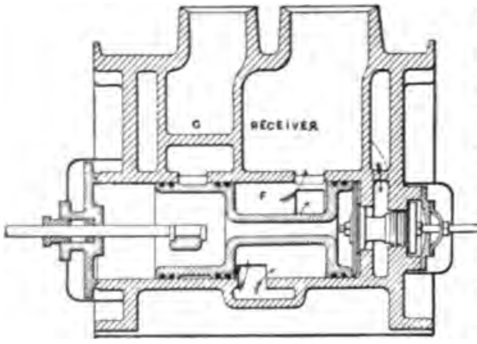


Fig. 43.

It will thus be seen that the intercepting valve never moves automatically since it is entirely under the control of the engineman. Furthermore, the intercepting valve can be prevented from moving as the lever is drawn back from full gear, by closing a valve in the steam pipe *a* Fig. 41. The piston in the cylinder C will then remain stationary and the engine will continue to work as a simple engine, at all points of cut-off.

The object of the reversing mechanism in the cab is to relieve the engineman of the necessity of converting the engine from single expansion to compound action by hand. The hand arrangement is present, however, and can be used in the event of any accident occurring to the reversing cylinder.

These engines are especially adapted to freight service.

Schenectady Compound. The compound locomotive built by the Schenectedy Locomotive Works is of the two-cylinder type. The general construction and arrangement of the cylinders and front end is similar to that of the Richmond locomotive as illustrated by Fig. 31. The difference lies in the design of the intercepting valve which is shown in section in Figs. 44 and 45.

Fig. 44 is a vertical section through the saddle and intercepting valve (low-pressure cylinder), and shows the intercepting and separate exhaust valve in the position taken when the engine is working simple.

Fig. 45 shows the same section through the low-pressure cylinder saddle, as in Fig. 44, and shows the intercepting and separate exhaust valves in the position when the engine is working compound.

With the arrangement of valves shown in these figures, the engine can be started and run either compound or simple, and can be changed from compound to simple or from simple to compound at the will of the engineer, with any position of throttle, and at any point of cut-off. The part which each valve does in accomplishing this is as follows:

The separate exhaust valve when open allows the steam to exhaust directly from the high-pressure cylinder to the atmosphere without going through the low-pressure cylinder, thus working the engine simple, and when closed causes the steam from the high-pressure cylinder to go through the low-pressure cylinder, thus working the engine compound. The intercepting valve closes the passage between the cylinders when the separate exhaust valve is open, so that steam cannot go from the high-pressure cylinder to the low-pressure cylinder, and it admits steam to the low-pressure cylinder directly from the dry pipe through the reducing

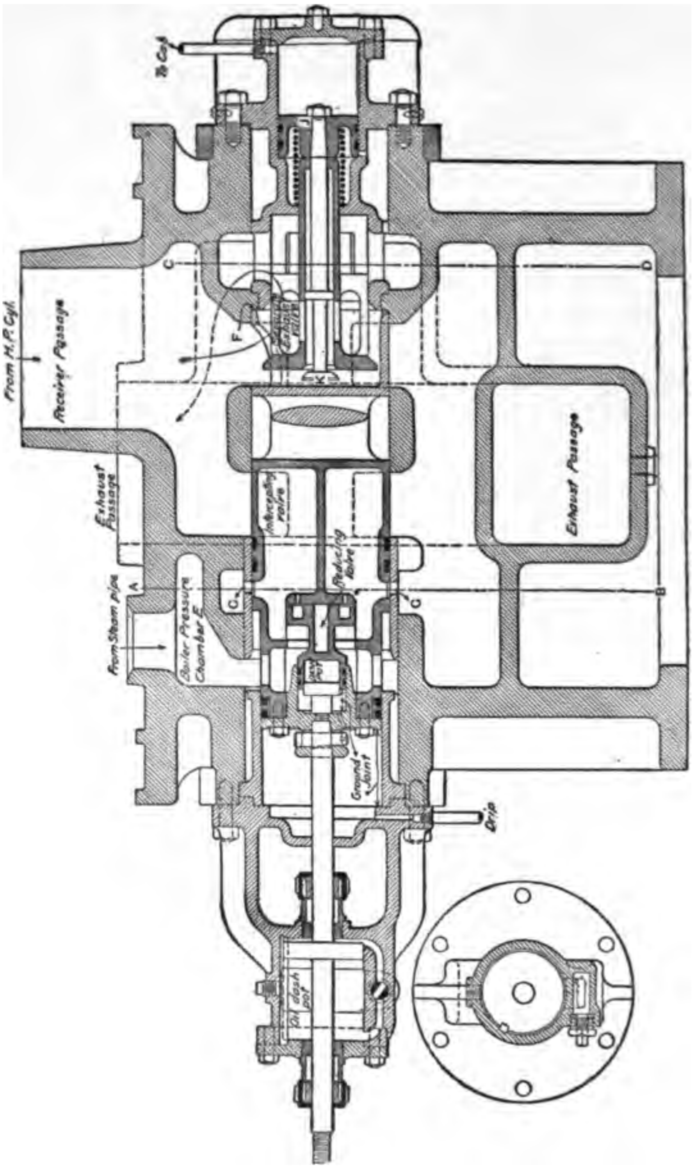


Fig. 44.

valve. When the separate exhaust valve closes, the intercepting valve opens the passage between the cylinders and cuts off the supply of steam from the dry pipe to the low-pressure cylinder.

The reducing valve works only when the engine is running

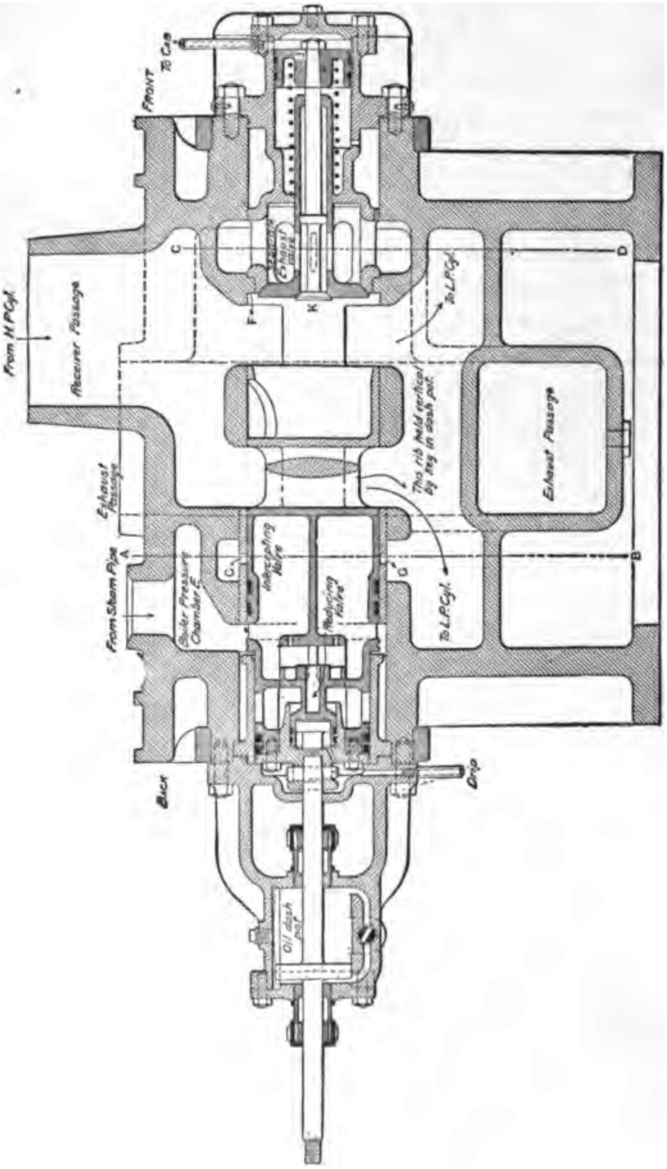


Fig. 45.

ple and throttles the steam passing through it, so that the ssure of steam going to the low-pressure cylinder is about one lf the steam pressure in the dry pipe.

The intercepting and reducing valves are worked automatically by the steam pressures acting on the difference of areas of the ends of the valves, and their movement is cushioned by dash pots. The separate exhaust valve is operated by the engineer, by means of a three-way cock in the cab. To open the separate exhaust valve, the handle of the three-way cock is thrown so as to admit air or steam pressure against the piston J. Pulling the handle back relieves the pressure against J; and the spring, which is shown in the figures, shuts the valve.

All the engineer ever has to do in connection with the operation of the valve is to pull the handle of a three-way cock in the cab, one way or the other, according as he wishes the engine to run simple or compound. The engineer uses this handle under the following conditions:

First, to start simple. Under ordinary conditions this is not necessary, but if the maximum tractive power of the engine is needed to start a heavy train, the engineer pulls the handle of the three-way cock so as to admit pressure on the piston J. This will force the piston J into the position shown in Fig. 44, which opens the separate exhaust valve and holds it open. As soon as the throttle is opened, steam at boiler pressure enters the chamber E and forces the intercepting valve against the seat F, as shown in Fig. 44. Steam enters the high-pressure cylinder and is exhausted through the receiver pipe and separate exhaust valve to the atmosphere, as shown in Fig. 44. Steam also enters the low-pressure cylinder from chamber E, through the reducing valve and ports G, shown in Fig. 44, and is exhausted in the usual way. The steam is prevented from reaching the low-pressure cylinder at boiler pressure, by going through the reducing valve. As will be seen from Fig. 44, the valve is partly balanced by the cylinder open to the atmosphere, and the boiler pressure acting on the unbalanced area throws the valve to the right. When the pressure on the right of the valve becomes high enough it will throw the valve to the left, because it acts on the whole area of the valve, and, in so doing, throttles the steam to the proper pressure for the low-pressure cylinder.

When the engineer wishes to change the engine from running simple to running compound, he pushes the handle of the three-way cock to its first position, which relieves the pressure on the right of the piston J, and the spring throws that piston to the right, into the position shown in Fig. 45, closing the separate exhaust valve. As soon as this valve is closed the pressure in the receiver rises and presses the intercepting valve to the left against the pressure in chamber E, which only acts on an unbalanced area of the valve. The receiver pressure holds the intercepting valve to the left, as shown in Fig. 45, closing the ports G and opening a free passage from the high-pressure cylinder to the low-pressure cylinder and the engine works compound.

It will be noticed that, while working compound, which is the usual way of working the engine, the intercepting and reducing valves are both held against ground joint seats, which prevent the leakage of steam that may have leaked past the packing rings.

Now with the engine running compound, if the engineer wishes to run the engine simple, because of a heavy grade, he pulls the handle of the three-way cock the same as for starting simple. This will open first the by-pass valve K, and then the separate exhaust valve, the by-pass valve relieving the pressure more gradually than if the large exhaust valve were opened at once. As soon as the separate exhaust valve is open the pressure in the receiver drops and the intercepting valve is forced against the seat F, by the pressure in chamber E, and the engine runs simple as before. When the grade is passed, the engineer pushes the handle of the three-way cock over and the engine begins to work compound. To start the engine compound the separate exhaust valve is left closed, as in Fig. 45, and, when the throttle is opened, the intercepting valve will be forced against the seat F, by the pressure in chamber E, as shown in Fig. 44. The low-pressure cylinder will then take steam through the ports G, and the high-pressure cylinder will exhaust into the receiver for a few strokes of the engine. This will raise the pressure in the receiver and force the intercepting valve into the position shown in Fig. 45, closing the ports G, and the engine will run compound.

The combination of the automatic intercepting valve with the separate exhaust valve, permits the engine to be changed from simple to compound, and the reverse, very smoothly and without danger of jerking the train.

Brook's Two-Cylinder Compound. This engine has the cylinders arranged as in the previously described engines. The variation is found in the construction of the intercepting valve, which is shown in section in Fig. 46.

The combined valve A admits live steam at reduced pressure to the low-pressure cylinder, this pressure being regulated in such ratio as desired. The intercepting valve B at the same time automatically closes and prevents the live steam from working against the high-pressure piston; the reducing valve remaining open until such time as the pressure in the receiver pipe on the high-pressure side of the intercepting valve becomes equal to or slightly in excess of that on the low-pressure side. The pressure regulating valve automatically closes and the intercepting valve opens simultaneously,— the first, cutting off the supply of live steam to the low-pressure cylinder; the second, opening connection between the two ends of the receiver and allowing the high-pressure exhaust steam to act directly on the low-pressure piston and at the same time locking the pressure regulating valve upon

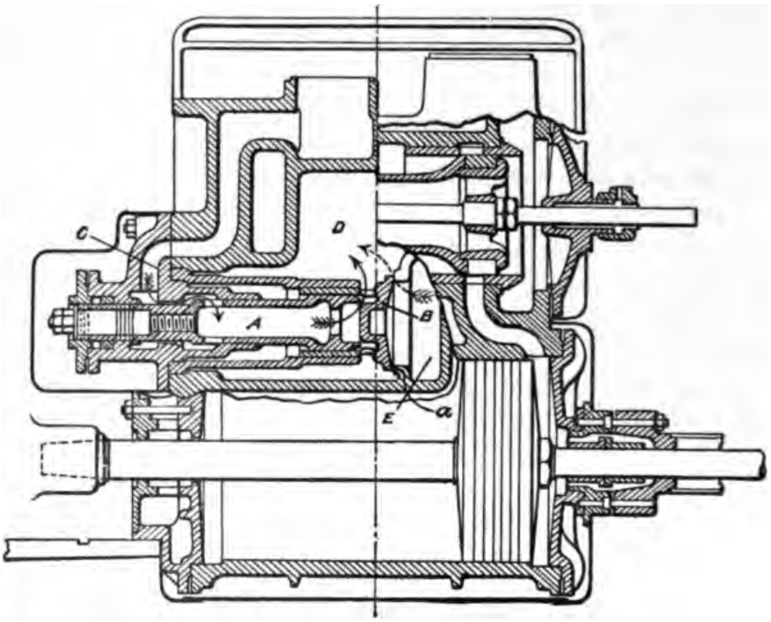


Fig. 46.

its seat and preventing the further admission of direct steam to the low-pressure cylinder. These valves remain in this position during the time the throttle valve is open. In order to give the engineman full command of the locomotive at all times, controlling valves are provided in the receiver. These are usually placed upon the bottom of the receiver, and are connected to the cab by suitable levers; they may, if desired, be of larger area and arranged in the upper portion of the receiver, connected with the exhaust pipe and arranged to work automatically in combination with the intercepting valve, so that the locomotive can be worked as a simple engine when required. However, on account of the arrangement of the combined admission and pressure regulating valve, which at all times, when necessary, admits sufficient steam to the low-pressure cylinder to give the locomotive its maximum power, the use of such a separate exhaust valve, whereby the engine can be worked simple for long periods, has been found in practice unnecessary, the arrangement of the admission and pressure regulating valve previously referred to, automatically performing all the requirements of a simple locomotive.

This valve operates as follows: Live steam acts upon the high-pressure piston in the usual manner. At the same time steam is admitted to the high-pressure end of the pressure regulating valve A through the connecting pipe C, causing the valve to open, as shown in the engraving, passing thence through the hollow portion of the valve, causing the intercepting valve to automatically close against its seat *a*. This steam flows through the passages of the intercepting valve into the low-pressure end of the receiver D and, acting upon the large end of the pressure-regulating valve, causes it to partially close as soon as the requisite pressure is obtained. The amount of steam admitted is regulated by the pressure regulating valve, and an even pressure is maintained in the receiver, the action being similar to that of the sleeve of the Richmond intercepting valve Figs. 33 to 37. The reduced pressure steam thus admitted to the receiver acts upon the low-pressure piston in the usual manner. As soon, however, as the high-pressure cylinder has exhausted sufficient steam into the high-pressure end of the receiver E to overbalance the intercepting valve, this valve opens automatically, at the same time locking the pressure regulating valve against its seat. The exhaust steam from the high-pressure cylinder then flows through the receiver as shown by the dotted arrow and acts directly upon the low-pressure piston. The pressure of this exhaust steam, even when considerably reduced, is sufficient to keep the pressure-regulating valve closed through the action of the combined valves at all times.

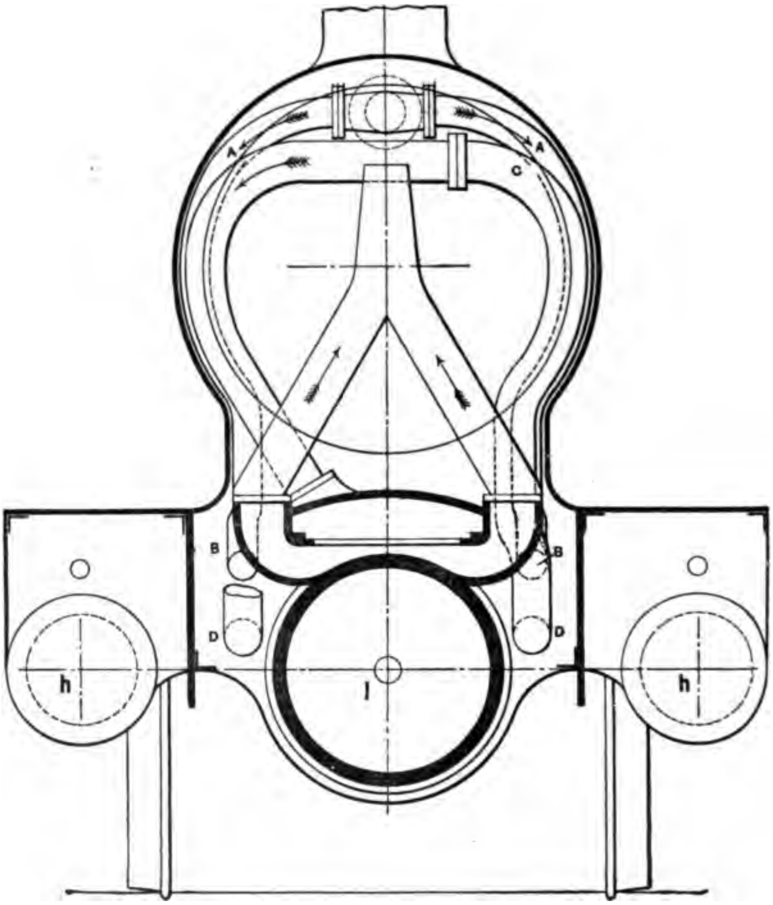


Fig. 47.

Three-Cylinder Compounds. The use of the three-cylinder compound locomotive has been confined almost exclusively to European railroads. The cylinders are arranged across the engine as shown in Fig. 47 which is known as the Webb system. In this figure, *h h* are the high-pressure cylinders, which are placed so that the centers are in a transverse line about four feet back of the front tube sheet, and are connected to the second pair of driving wheels. The low-pressure cylinder *l* is placed beneath the smokebox, and is connected to the forward pair of driving wheels. The course of the steam from the boiler is through the pipes A A to B B, and thence back to the high-pressure cylinders. The exhaust from these cylinders is led through the pipes D D, and thence around the smokebox through the two pipes C to the low-pressure steam chest. The course of the exhaust from the low-pressure cylinder is clearly indicated in Fig 47. The disposition of the cylinders and steam pipe is essentially the same in the Webb compounds for passenger and freight service. The most noticeable peculiarity of the system is the absence of driving connection between the high-pressure and low-pressure axles, there being no coupling rods on engines having two pairs of driving wheels.

A compound locomotive of this type was purchased by the Pennsylvania Railroad and put into service in 1899. The results of practical trials with the heavy trains used in the United States were satisfactory in economy, but showed unsatisfactory hauling power. It has been found difficult to start the ordinary weight of train with this engine, owing to the slipping of the drivers, which were not provided with parallel rods. When the trains are light the engine works with the most excellent economy, and shows a decided saving in fuel. The reports from the London & Northwestern Railway of England, where these engines have been principally used, show that they are satisfactory.

A compound locomotive having one high and two low pressure cylinders was built in France. The general arrangement of the cylinders was the same as shown in Fig. 47, except that they were in line and the high-pressure cylinder was between the frames and beneath the smokebox. The course of the steam is first to the high-pressure cylinder from which it is exhausted into a receiver and thence distributed to the two low-pressure cylinders. In this case the central cylinder is of nearly the same diameter as the outside ones and not larger, as in Fig. 47.

The use of three-cylinder compound locomotives is being discontinued.

Four-Cylinder Compounds. There are two types of four-cylinder compound locomotives built in the United States. In each case there are two high and two low-pressure cylinders. In one, the cylinders are set in pairs on each side, with one cylinder above the other. In the other case the cylinders occupy the same position but are set tandem.

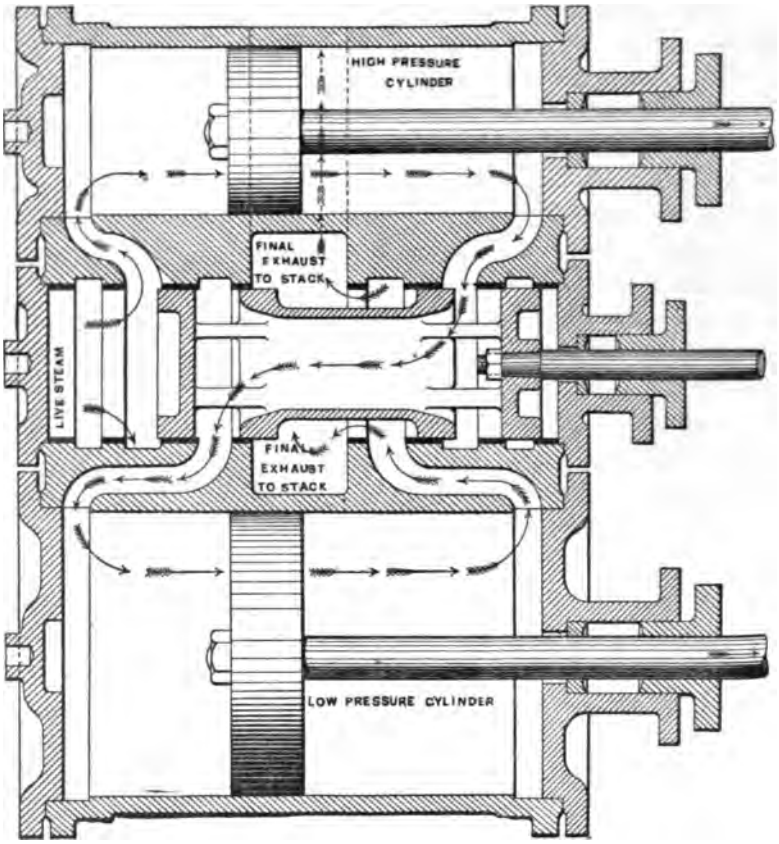


Fig. 48.

Unlike the two-cylinder compound an intercepting valve is not needed since there is always a high-pressure cylinder acting upon a crank that is not on the dead center. Hence the engine can always be started.

The four-cylinder compound locomotive that has been most extensively used in the United States, is that built by the Baldwin Locomotive Works, and has the two cylinders set one over the other.

Fig. 48 shows the arrangement of the cylinders in relation to the valve.

The valve employed to distribute the steam to the cylinders is of the piston type, working in a cylindrical steam-chest located in the saddle of the cylinder casting between the cylinders and the smoke-box and as close to the cylinders as convenience will permit.

As the steam-chest must have the necessary steam passages cast in it and finished accurately to the required sizes, the main passages in the cylinder casting leading thereto are cast wider than the finished ports. The steam-chest is bored out enough larger than the diameter of the valve to permit the use of a hard cast-iron bushing. This bushing is forced into the steam-chest under such pressure as to prevent the escape of steam from one steam passage to another except by the action of the valve. Thus an opportunity is given to machine accurately all the various ports, so that the admission of steam is uniform under all conditions of service.

The valve, which is of the piston type, is double and hollow, and controls the steam admission and exhaust of both cylinders. The exhaust steam from the high-pressure cylinder becomes the supply steam for the low-pressure cylinder. As the supply of steam for the high-pressure cylinder enters the steam-chest at both ends, the valve is in perfect balance, except for the slight variation caused by the area of the valve-stem at the back end.

As indicated by the arrows of Fig. 48, the two pistons move in unison and are attached to the same crosshead. This is a source of weakness in this construction. It is impossible to obtain the same total piston pressure on each of the two rods. The result is that the unequal pressures tend to tilt the crosshead, bending the rods at the junction with the crosshead and tending to break them at that point.

As the high-pressure cylinders of this class of locomotive are considerably smaller than the single cylinders of the ordinary type of the same rated capacity, it is evident that the starting power of the high-pressure cylinders alone, is less than that of a single expansion engine of the same rated capacity. Hence, although the cranks are always in a position to start a train, it is obvious that in starting these locomotives with full trains from a state of rest, it is necessary to admit steam to the low-pressure cylinder as well as to the high-pressure cylinder, which is accomplished by the use of a starting valve (Fig. 49). This is merely a by-pass valve which is opened to allow steam to pass from one end of the high-pressure cylinder to the other end and thence through the exhaust to the low-pressure cylinder. This is more clearly shown at E in Fig. 50 The same cock acts as a cylinder cock for the high-pressure cylinder and is operated by the same lever that operates the ordinary cylinder cocks, thus making a simple and efficient device, and one that need not become disarranged. This valve should be kept shut as much as possible, as its indiscriminate use reduces the economy and makes the locomotive "logy."

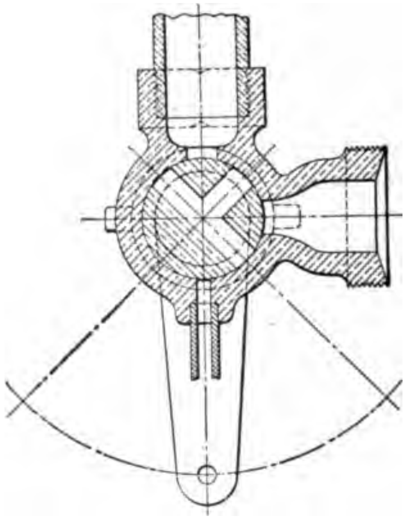
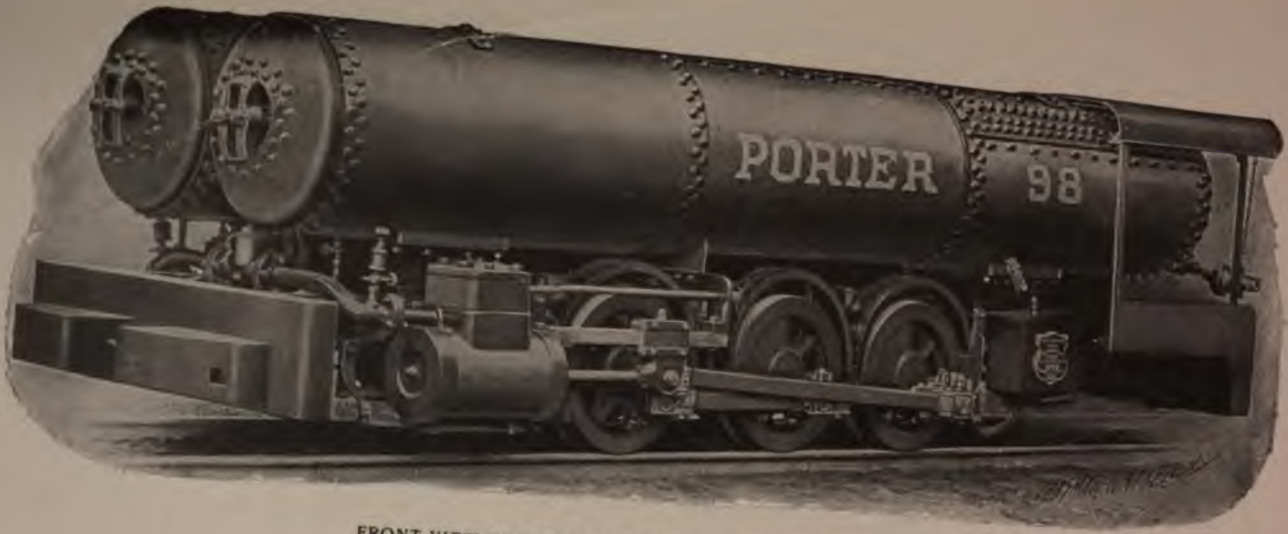


Fig. 49.

As is usual in all engines, air valves are placed in the main steam passage of the high-pressure cylinder. Additional air valves, marked C and C′ in Fig. 50, are placed in the steam passages of the low-pressure cylinders to supply them with sufficient air to prevent the formation of a vacuum, which would draw cinders into the steam-chest and cylinders.

When starting the locomotive from a state of rest, the engineer should always open the cylinder cocks to relieve the cylinders of condensation, and as the starting valve is attached to the cylinder cocks, this movement also admits steam to the low-pressure cylinder and enables the locomotive to start quickly and freely.



FRONT VIEW PORTER COMPRESSED AIR LOCOMOTIVE.

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ASTOR, LENOX AND
TILDEN FOUNDATIONS
R L

The second form of four-cylinder compound locomotive in use in the United States is the tandem type, built by the Brooks Locomotive Works and illustrated in section in Fig. 51.

The low-pressure cylinders and steam chests are attached to the smokebox in the usual place and manner and the high-pressure cylinders and steam chests are attached to the forward end of the low-pressure cylinders and have steam chests communicating with the steam chests of the low-pressure cylinders. The steam is supplied to the high-pressure valve chests through connecting pipes, and the low-pressure cylinder exhausts through the saddle in the usual way. The high-pressure steam chests are fitted with hollow piston valves having internal admission, the low-pressure

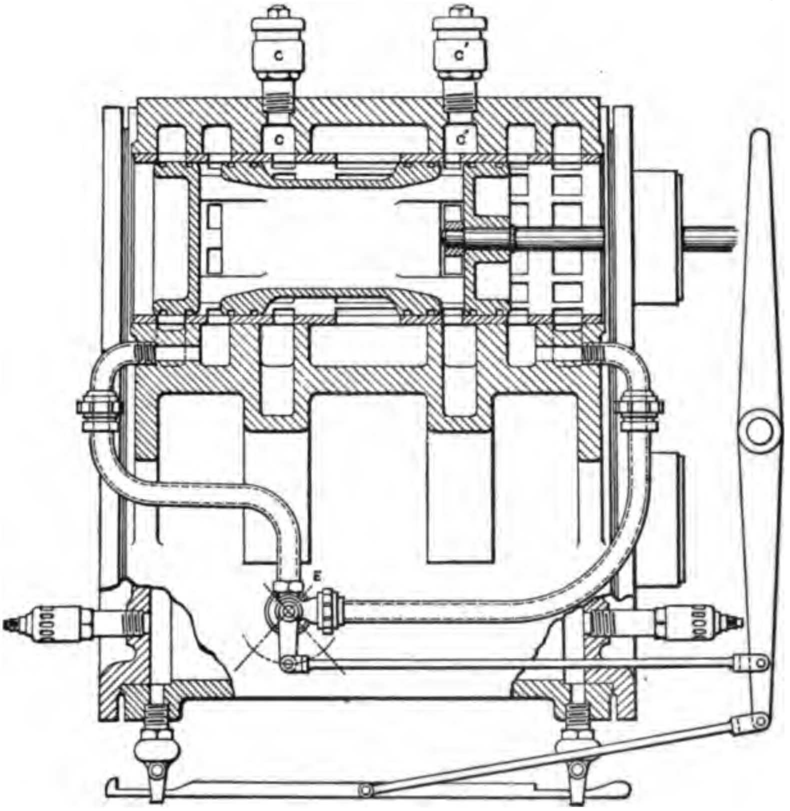


Fig. 50.

steam chests being also fitted with internal admission piston valves as shown in Fig. 51.

The pistons of the high and low-pressure cylinders are arranged upon the same rod, and the intermediate head between the high and low-pressure cylinders is fitted with a metallic packing. The low-pressure steam chest is provided with a reducing and starting valve connecting with the high-pressure steam pipe. This valve is permitted to operate automatically when the reverse lever is in full forward or full back gear. In the intermediate positions of the lever, this reducing valve is locked to its seat so that it is rendered inoperative, and the engine must necessarily work compound at all times under all conditions of steam pressure when the reverse lever is in any other position than full gear. The use of this combined starting and reducing valve permits the introduction of steam into the low-pressure cylinder at an equivalent to the maximum pressure obtained in this cylinder when the engine is working compound.

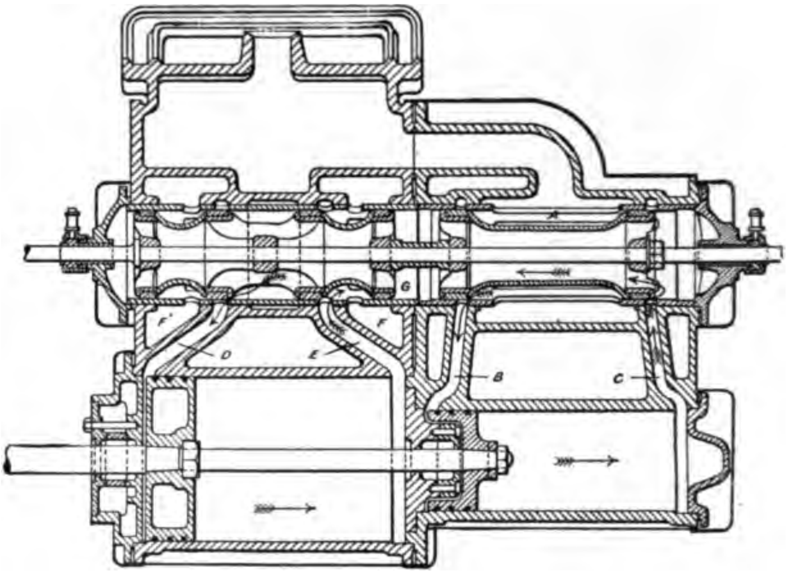


Fig. 51.

As soon as the engine has made one revolution and the receiver is charged with exhaust steam from the high-pressure cylinder, the starting valve becomes inoperative, thereby causing the engine to work compound.

Referring to Fig. 51, it will be seen that the pistons are at the end of the stroke and are about to move in the direction indicated by the arrows. The valves of the two cylinders are attached to the same stem and are admitting steam to the left-hand ends of the two cylinders and exhausting it from the right. Live steam enters the annular space A about the high-pressure valve and passes down into the port B as indicated by the arrow. At the same time exhaust steam passes out through the port C and follows the direction of the arrow into the interior of the two valves. After traveling to the center of the low-pressure valve it follows the direction of the arrow and enters the port D and is admitted to the left of the low-pressure piston.

The exhaust steam from the low-pressure cylinder is, at the same time, escaping through the port E into the passage F, whence it is discharged through the exhaust nozzle into the atmosphere.

For the opposite ends of the cylinder the high-pressure exhaust enters the interior of the valve through the annular space G, and the low-pressure exhaust escapes into the passage F′ that corresponds to and is connected with F.

Very few of these locomotives have been built.

In the designing of compound locomotives it is important that two points should be carefully determined. One is that the size of the high-pressure cylinder should bear the proper ratio to the cylinder of the single expansion engine that it is intended to replace. The other is that the proper ratios should exist between the diameters of the high and low-pressure cylinders on the engine that is to be designed.

It has been found that, for the same steam pressures in the boiler and the same weights on the driving wheels, the area of the piston of a simple expansion engine should be to that of the high-pressure cylinder of a compound locomotive as 1 to 1.17. That is to say the diameter of the high-pressure cylinder of a com pound locomotive should be seventeen per cent. larger than that of the simple expansion engine which it is intended to supplant.

This rule applies to two-cylinder compounds. In the case of four-cylinder compound locomotives a lower ratio is used. That is to say, the sum of the areas of the two high-pressure pistons are made about 2.6 per cent. larger than one piston of simple expansion engines of the same power.

In the matter of the proportioning two cylinders of a compound system there has been a wide range of practice.

For two-cylinder compounds the ratios of piston areas vary from 1 to 2.74 for small engines to 1 to 1.77 for large engines. For two-cylinder compound locomotives in the United States a ratio of 1 to 2.1 may be taken as the prevailing practice and is usually recommended. For four-cylinder compounds the usual ratio is 1 to 3.

Logging Locomotives. The locomotives ordinarily known as logging locomotives are of two types. One is built after the general pattern of the four-wheeled switching locomotive with the exception that the wheels have broad grooved tires a foot or so in width that are adapted to running upon a track formed of logs placed end to end. The other is known as the Shay locomotive and is fitted to run on ordinary rails. Such an engine is shown in Fig. 52. It is built on three four-wheeled center-bearing swiveled trucks, the wheels of which are driven by bevel gearing attached to the right-hand wheels of each truck with steel pinions meshing into them, carried by a shaft running in bearings attached to the journal boxes, and extending from axle to axle of each truck. The power is communicated to these pinion shafts with flexible couplings extending from the engines, which are placed vertically on the side of the boiler. This arrangement leaves each truck free to adjust itself to curves and irregularities of the track.

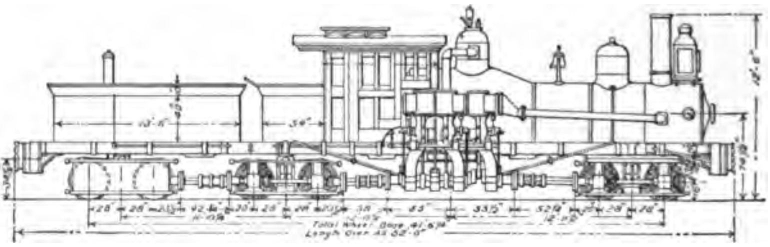


Fig. 52.

The three trucks here spoken of include the tender truck, which is a driving truck also. The trucks are built of steel, are equalized and have coil springs.

The object of this construction is to have the shortest possible rigid wheel base and the longest possible flexible wheel base, thus utilizing all the weight for traction. It is possible to work the locomotive on very sharp curves, the one illustrated running easily on a 65-degree curve. Its use is confined to roads having heavy grades and sharp curves, and it is restricted to low speeds.

The frames of both engine and tender are made of 10-inch I beams, one on each side, that of the engine being strengthened by a truss rod as shown. Steam brakes are provided to act on part or all of the drivers, either separately or together.

Rack Locomotives are used on roads where the grades are too steep to be operated by the ordinary traction locomotive. The adhesion between the wheel and the rail of such an engine cannot be taken at more than 25 per cent. of the weight. Hence when the grade becomes so steep that the resultant of gravity acting parallel to the rails becomes equal to twenty-five per cent. of the weight of the locomotive it will be impossible for it to advance. Such a grade is reached when the rise is 1320 feet to the mile. Practically it is much less than this. So on a grade of one-half of this the engine could only hold, not haul, itself and a car equal to its own weight.

Hence for roads climbing mountains where the gradient is necessarily very steep the rack locomotive is used. Such an engine is shown in side elevation in Fig. 53.

The weight of the locomotive is carried on smooth rails in the ordinary manner, and while the grade lies within the limits of its weight to overcome, it is propelled by driving wheels like other engines. But when the grade becomes too steep, the gear wheel A is brought into mesh with a rack rail laid in the center of the track between the other two. The teeth of this gear engage with those of the rack and propel the engine independently of the power developed at the driving wheels and which would be insufficient to do the work.

Between the two main driving axles, is another driving axle, carrying the gear A which meshes with the rack. This gear axle is driven, through reducing gearing by a pair of inside cylinders. In addition to the two main axles there is another rear axle carrying, besides its pair of wheels, a brake pinion. The crankpins are made spherical so as to afford the necessary flexibility when rounding sharp curves. All four cylinders have the same diameter and length of stroke and are independent of one another so far as steam supply is concerned. When running along the ordinary track the inner cylinders have no steam supply and do not perform any work.

In the matter of brakes there are the ordinary brake-shoes on the driving wheels and strap brakes on the rear locomotive truck axles and air brakes on the cars.

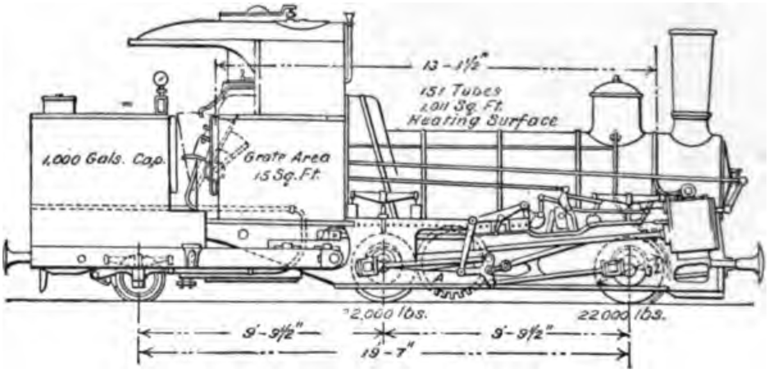


Fig. 53.

Such an engine, as that shown in Fig. 53, is calculated to haul 40 tons up a 90 per cent. grade at a speed of five miles an hour.

This class of engine is extensively used on the mountain railroads of Switzerland. It is also used on the roads running up Mt. Washington and Pike's Peak in the United States.

Traction. On page 43 of Part I. of Locomotive Boilers and Engines a formula was given for the calculation of the size of the cylinder to be used with a locomotive of given dimensions. This formula is based upon the tractive power of a locomotive or the amount of pull which it is capable of exerting upon the tread of its driving wheels.

The formula for the calculation of the tractive power of a locomotive is

$$T = \frac{d^2 p s}{D}$$

in which

d = the diameter of the cylinder in inches,
p = the mean effective pressure in pounds per square inch,
s = the stroke in inches,
D = the diameter of the driving wheels in inches,
T = the tractive power or pull at the rail in pounds.

This formula is based upon the fact, that, neglecting friction, the work done in both cylinders during any period, such as one revolution, is equal to that done at the circumference of the driving wheel during the same time. It is convenient and practical, as it gives the hauling power of the locomotive when the mean effective pressure in the cylinders is known. The tractive power by this formula includes the power necessary to move the entire mechanism of the locomotive and the locomotive itself. It is, in fact, the entire work done in the cylinders reduced to an equivalent pull on the rail. In using it, a reduction must always be made for the internal friction of the engine and for the power required to move the engine and tender in order that the actual pull on the train itself may be determined.

This gives the average tractive power of a locomotive and not its starting power which should be taken at the maximum pull and not the average.

As the tractive power depends upon the mean effective pressure, and as the mean effective pressure varies with the point of cut-off, it is evident that the tractive power of a locomotive is not always the same. The effect of a variation of the point of cut-off in a stationary engine is explained in Steam Engine Indicators. It is more perfectly shown by Figs. 54 and 55. Fig. 54 represents a card taken from a locomotive at the moment of starting, where, with a boiler pressure of 180 lbs. per square inch, a mean effective pressure of 165 lbs. is obtained. Fig. 55 represents a card taken from the same locomotive after a speed of 57 miles an hour had been attained. In this card the mean effective pressure had fallen to 48 lbs. per square inch. Hence, in this case, the tractive power of the locomotive was only about 34 per cent., at 57 miles per hour, of what it was at starting.

Further, the rotative effect even with uniform cylinder pressure, is not constant but the maximum varies by about 15° on each side of the 45° point of the cranks.

To prevent slipping it may be stated that the average tractive force should not exceed 22 per cent. of the adhesive weight, as this will prevent the maximum rotative force exceeding the 25 per cent. used before in all but the $\frac{1}{8}$ and $\frac{1}{4}$ cut-offs, and, as the speeds are generally high at these points the inertia of the wheels, etc., would probably prevent slipping at the maximum points.

Train Resistance. The resistance offered by a train per ton of weight varies with the speed. This resistance also varies with the kind of car hauled, the condition of the track, and the condition of the journals and bearings.

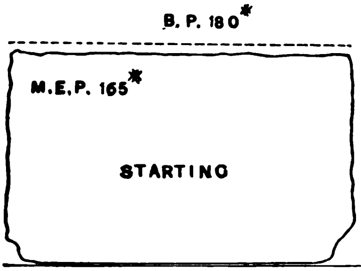


Fig. 54.

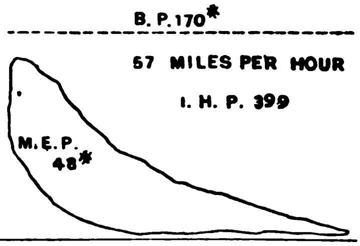


Fig. 55.

Taking the average condition of American rolling stock, train resistance is probably best represented by the formula published in the *Engineering News* which is

$$R=\frac{S}{4}+2$$

in which

R = Resistance in pounds per net ton (2000 lbs.) of load.

S = Speed in miles per hour.

The force for starting is, however, about 20 pounds per ton, which falls to 5 pounds as soon as a low rate of speed is attained.

The resistance due to grades is expressed by the formula

$$R' = 0.38\,M.$$

in which

R' = resistance in pounds per net ton of load,
M = Grade in feet per mile.

The coefficient $0.38 = \frac{2,000}{5,280}$.

(See Mechanics Part 1.)

The resistance due to curves is generally taken at from 0.5 to 0.7 pounds per ton per degree of curvature. Taking the latter value, and assuming that locomotives, on account of their long, rigid wheel base, produce double the resistance of cars, we have

$$R'' = 0.7\ C \text{ for cars,}$$
$$= 1.4\ C \text{ for locomotives,}$$

in which

R'' = Resistance due to curvature in pounds per net ton,
C = Curvature in degrees.

EXAMPLE FOR PRACTICE.

What will be the total resistance of a train consisting of a locomotive weighing 140,000 pounds and cars weighing 260,000 pounds, when running at a speed of 12 miles per hour up a grade of .8 of one per cent. and on a curve of 6 degrees?

Ans. 5,344 pounds.

These resistances do not take into account that added by the acceleration of the train. This may be expressed by the formula;

$$R''' = 0.0132\ V^2$$

in which

V = speed attained in one mile, expressed in miles per hour, starting from rest.
R''' = Resistance due to acceleration in pounds per net ton.

Locomotive Rating. As a locomotive is intended to haul loads and as it is doing its work most economically and efficiently when it is working to its full capacity, it becomes necessary to determine how much it can haul. The determination of the weight of the train to be hauled by a locomotive is called the rating of the locomotive. This weight will vary for the same locomotive under different conditions. The variation is caused by differences in grade, curvature, temperature condition of the rail, and amount of load in the cars. The variation due to the differences of car resistance arising from a variation of the conditions of the journals and lubrication is neglected because of the assumption of a general average of resistance for the whole.

The usual method of rating locomotives at present is that of tonnage. That is to say, a locomotive is rated to haul a train weighing a certain number of tons over a division. This is preferred to a given number of loaded or empty cars because of the indefinite variation in the weights of the loads and of the cars themselves.

In the determination of a locomotive rating there are several factors to be considered. These are: the power of the locomotive and its adhesion to the rails, the resistance of trains including the normal resistance on a level and that due to grades and curves; the value of momentum; the effect of empty cars and the effect of weather and the seasons.

The power of the locomotive and its adhesion to the rails have already been considered. From the formulæ given the traction can be calculated with approximate accuracy from data already at hand.

There are three methods in use for obtaining a proper tonnage rating: first, the practical method which consists in trying each class of engine on each critical or controlling part of the division and keeping on trying to see what can be hauled until the limit is reached. Second, a more rapid and satisfactory method is to determine the theoretical rating and work with that. Third, the most satisfactory method is to first determine the theoretical rating and then check these figures by the results of actual trials.

The value of the momentum is a very important element in the determination of the tonnage rating of locomotives on the majority of railroads. In mountainous regions, with long, heavy grades there is little opportunity to take advantage of the force due to momentum, while on undulating roads it may be utilized to the greatest advantage. A velocity approach to a grade, when it can be reduced in ascending the same, enables the engine to haul greater loads than it could without such assistance. Hence, stops, crossings, curves, water tanks, etc., will interfere with the make-up of a train if so located as to prevent the use of momentum, and it is necessary to bear all these points in mind when figuring the rating for an undulating division.

The ordinary method of allowing for momentum is to deduct the velocity head from the total ascent and consider the grade easier by that amount.

Suppose, for example, that 5,000 feet of 1 per cent. grade were so situated that trains could approach it at speed. The total rise of the grade would be 50 feet, but of that 15 feet could be overcome by the energy of the train, leaving 35 feet that the train must be raised by the engine. A grade in which the rise is 35 feet in 5,000 would be a 0.7 per cent. grade, so that if the engine could exert sufficient force to overcome the train resistance and that due to a 0.7 per cent. grade, the train could be lifted the remainder of the height by its kinetic energy. In this case the 5,000 feet of 1 per cent. grade could be replaced by 5,000 feet of 0.7 per cent. grade, and the effect on the load hauled by the engine would be the same, if in the latter case the energy of the train were not taken into account. Since the height to which the kinetic energy raises the train is independent of the length of the grade, its effect becomes far less when the grades are long than when short. Thus, for 1 per cent. grade 1,000 feet long, since the total rise is only 10 feet, the kinetic energy would be more than sufficient to raise the weight of the train up the entire grade, leaving only the frictional resistances to be overcome by the engine; whereas, if the grade were 50,000 feet in length or a total rise of 500 feet, the energy of the train would only reduce this by 15 feet, leaving 485 feet or the equivalent of a 0.99 per cent. grade to be overcome by the engine, a reduction not worth considering.

It is thus seen that the length of the grade exerts a great influence on the value of the momentum.

Within ordinary limits the following formula can be used with fairly approximate results.

$$T = \frac{c^2\ s\ P\ m}{d\left\{R^1 + \frac{a}{2.64}\right\}\left\{1 - \frac{V^2 - v^2}{0.00566\ a\ l\ (1 + \frac{2.64\ R^1}{a})}\right\}}$$

where c represents the diameter of cylinder in inches.

s represents stroke in inches.

$P\ m$ represents the mean effective pressure.

d represents diameter of driver in inches.

R^1 represents resistance in pounds per ton on level due to friction, air, curves and velocity (say eight pounds per ton).

R^2 represents resistance in pounds per ton due to gravity

$$= \frac{a}{2.64}.$$

a represents grade in feet per mile.

l represents length of grade in feet.

V represents velocity in miles per hour at foot of grade.

v represents velocity in miles per hour at top of grade.

T represents tons (including engine and cabin car) which can be hauled over a grade with velocities of V and v.

Thus with an engine having 17 in. by 24 in. cylinders and 62 in. wheels and a velocity of 30 miles an hour, the formula gave a rating of 738 tons. On actual tests it was possible to haul 734 tons with a speed, at the top of the hill, of 10 miles an hour.

Where the grades are not too long it is well to make a table of engine ratings from the formula for several portions of the line of railway.

The effect of empty cars is to somewhat reduce the total tonnage of the train below what could be hauled if they were all loaded. The resistance of empty cars varies from 30 to 50 per cent. more per ton of weight than loaded cars. This refers to a straight and level track.

In using the formula on page 60 for train resistances, it should be taken to apply to loaded cars to which 40 per cent. may be added for empty cars. That is to say: if a train is composed of empty and loaded cars and it is found to have a certain resistance, 40 per cent. should be added to the portion of resistance due to the empty cars.

There is considerable difference of opinion regarding the allowance that should be made for the conditions of the weather, etc. The following is a fair allowance that has been found to work well in practice: 7 per cent. reduction for frosty or wet rails; 15 per cent. reduction for from freezing to zero temperature; 20 per cent. reduction for from zero to 20 degrees below.

The use of pushing or helping engines over the most difficult grades of an undulating track will increase the train load and reduce the cost of transportation.

The Tender consists of a separate car attached to the rear of the locomotive proper and is designed to carry the necessary coal and water. It consists of three essential parts: the running gear, the frame and the tank.

The Trucks. The running gear comprises the two trucks that are usually placed beneath American locomotive tenders. These trucks include the wheels, axles, oil-boxes and truck frames.

The wheels may be made of cast iron with a chilled tread or may have steel tires similar in form to those used on the driving wheels. These wheels are pressed upon the axles with an hydraulic pressure of from 35 to 50 tons. Fig. 56 shows a section of a cast iron wheel as pressed upon an axle. It consists of a tread A, the plate B and the hub C. The tread is of a standard shape and is shown with all dimensions in Fig. 16.

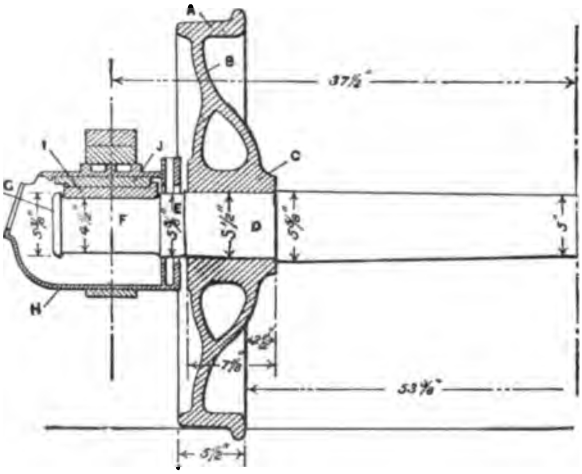
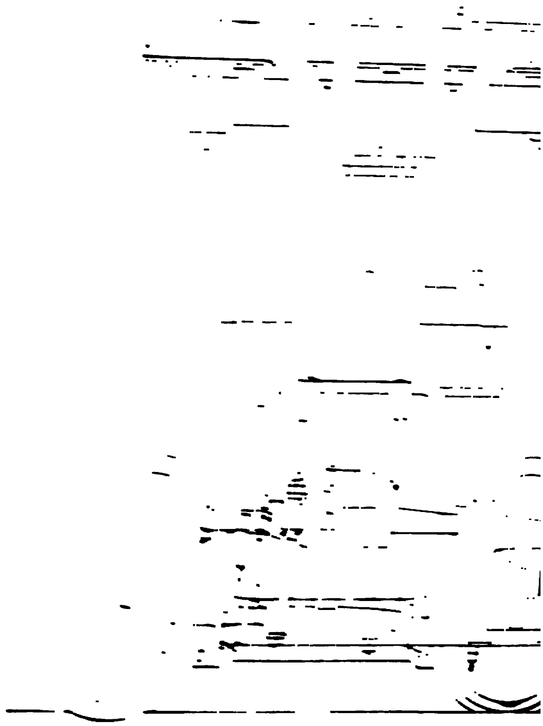


Fig. 56.

The axles are now almost invariably made of steel. They taper from a maximum diameter at the wheel-seat D to a smaller diameter at the center. Outside the wheel-seat there is a dust-guard bearing E with which a packing, placed in the spaces in the box about it, is in contact. This prevents the access of dust to the box from the back. Next to the dust guard comes the journal bearing F and beyond this is the collar G that holds the oil box in position on the axle.



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The center plate is carried by the transoms B which are, in turn, bolted to the side pieces or frames C. The frames rest upon the springs D that rest upon the hangers F swinging from the equalizers E that finally deliver the weight to the axle boxes.

The center-plate A may be of cast or malleable iron, a steel casting or pressed steel. It is merely a plate with a circular bearing upon which a similar plate fastened to the frame rests. In the truck shown, each transom is formed of an upper and lower member of flat steel. The upper member G, Fig. 59, is working under compression and the lower member H is under tension. The side bars C are formed of heavy pieces of steel to which are bolted the transoms and which are also fitted with pedestals of cast iron I at their outer ends in which the oil boxes are free to move up and down. These pedestals are tied together at the bottom by a pedestal brace K that is firmly bolted to each leg. These braces are themselves stayed by the cross-ties L L which also form a part of the transoms by being bolted thereto by the bolts M M.

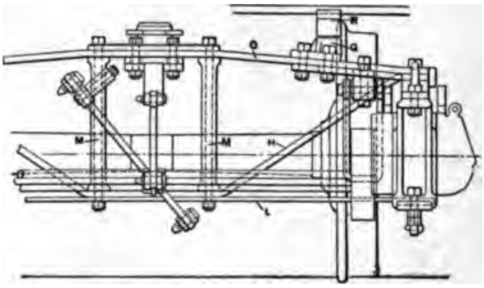

Fig. 59.

This truck differs essentially from the engine truck Fig. 18 in that the bearings are outside the wheels instead of being between the same. The equalizers E are, therefore, outside the wheels but on either side of the frame. They rest directly upon the oil boxes and carry the springs through the hangers F.

The tender truck also differs from the engine truck in that it is provided with brakes. The brakebeams are hung from the transom by the hanger N that is suspended from the piece O bolted to the upper bar of the transom and the gusset brace P by which the side pieces and transoms are prevented from varying their relative positions.

The brake levers may be arranged as shown in Fig. 33 or Fig. 36 of "Air Brakes." In Figs. 57 to 59 the method of Fig. 33 (Air Brakes) is followed.

As the frame is balanced on the center plate A, it would tip from one side to the other were not some means of preventing it interposed. This is done with the side bearing Q and R; the former being bolted to the transoms and the latter to the body bolster of the frame.

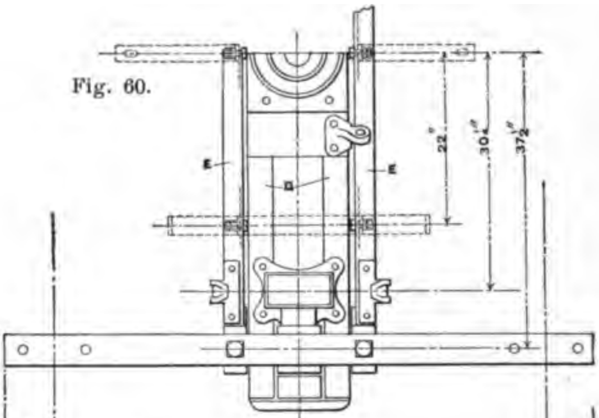

Fig. 60.

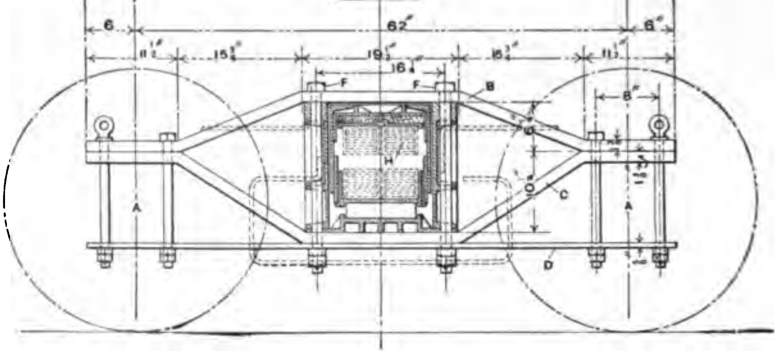

Fig. 61.

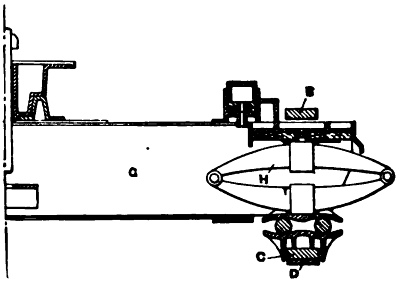

Fig. 62.

The second form of tender truck is shown in Figs. 60, 61 and 62. These show what is known as the diamond frame truck. The wheels, axles and oil boxes are the same as in the truck previously described. The oil boxes are, however, rigidly bolted in between the bars at A A. The side

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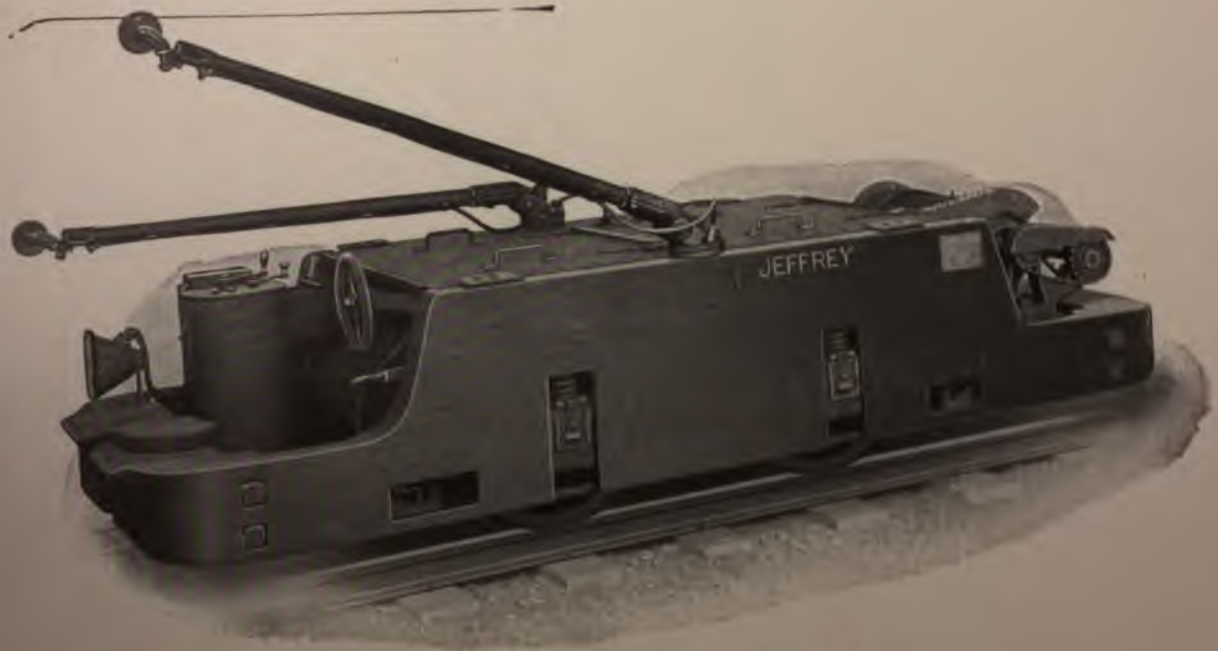


4-TON, INSIDE-WHEEL ELECTRIC LOCOMOTIVE.

Jeffrey Manufacturing Co.

frame is formed of three bars, B the upper arch bar, C the lower arch bar and D the pedestal tie-bar. The transoms E, are usually made of steel channels and are rigidly fastened to the side frames by the column bolts F. The center-plate is carried by a bolster G that rests upon the elliptic springs H. These are carried by seats bolted either directly to the lower arch bar or to a spring plank extending from one side frame to the other.

The third form of tender truck has a pressed steel frame. It is shown in Figs. 63, 64 and 65. Fig. 63 is a half side elevation and half section on the center. Fig. 64 is a quarter plan and a quarter horizontal section on a line with the axles. Fig. 65 is a half end elevation and half section through the center.

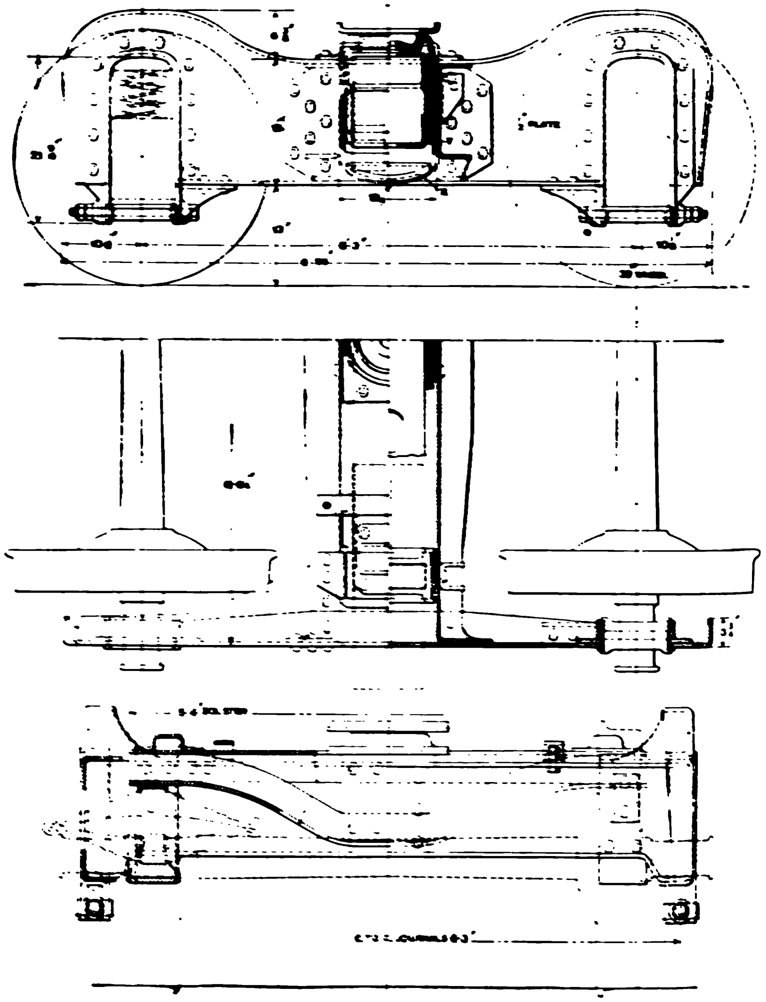
The peculiarities of this form of truck are the frames, transoms and bolster which are pressed out of steel plates and the use of two sets of springs. The pedestal jaw is deep enough to admit the oil box and on top of it there is a nest of coil springs to carry the frames. The elliptic springs upon which the bolster rests, are carried by U-shaped straps X that are supported by the transoms. The center plate is also of pressed steel.

Among the standards in use upon all American railroads are the brakeshoe and head shown in Fig. 66. The shoe A is held to the head C by the key B. The attachment of the brakehead to the brakebeam may be of any shape to suit the form of the latter.

The Frame of the tender was formerly made of wood but now, in most new work, steel is used. Such a tender frame is shown in Fig. 67. The construction must be simple and exceedingly strong in order to meet the requirements of the work to be done. The sills A are steel channels firmly riveted to end plates B by means of angles.

The other cross connections are the body bolsters C and a cross-tie D. Distortion is prevented by the diagonal braces E. The construction of the body bolster is shown in the cross-section where it will be seen to consist of an upper tension member F that is bent to make the connection with the side sills and a compression member G. The center-plate is bolted to the latter. At the front end next the engine there are steps H on each side and a rubbing plate I to protect the frame from wear at the point where it comes in contact with the engine. At the rear there is the coupler K for attaching the cars.

This frame must have ample strength to not only transmit all



Figs. 63, 64 and 65.

of the power, developed by the locomotive, to the train, but also must be able to sustain all of the blows and shocks that may be delivered to it in service. These shocks may be far in excess of anything that the locomotive is capable of developing.

This fact requires the connection between the engine and tender to be exceptionally strong. Yet it must have a certain amount of flexibility in order to not only relieve the shocks that may be delivered by the one to the other but also to permit the variations of alignment due to curving and those of height arising from a change of load on the tender.

A strong and satisfactory form of connection between the engine and tender is shown in detail by Fig. 68.

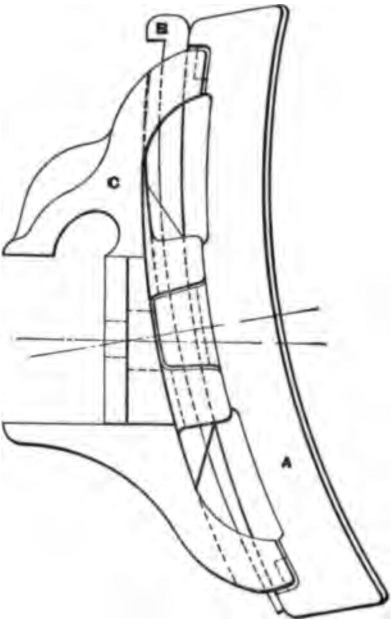


Fig. 66.

There are really three connections.

At the center there is a strong bar A shown by dotted lines that is 4 inches wide and $1\frac{1}{4}$ inches thick.

This is held by a large pin at each end in castings firmly bolted to the end piece of the engine and tender frames respectively. The holes in the bar are slightly elongated so as to permit of a moderate amount of compression of the spring in the buffing casting B that is bolted to the end or tail piece of the engine. The two side bars C C are merely safety connections. They are held by pins like the main drawbar A. The ends in the tender have long slotted holes so that the tender frame can turn as it may be necessary without putting any stress upon them. If, however, the central connection should be broken the ends of the slotted holes at once come to a bearing and further separation of the engine and tender is prevented.

Tanks. There is one form of tank used on locomotive tenders that is universal. It is the U-shaped as shown in half plan and longitudinal section in Fig. 69 and in cross section in Fig. 70. The open space between the two legs is used for the storage of the fuel and the tank itself for the water. Two minor variations in

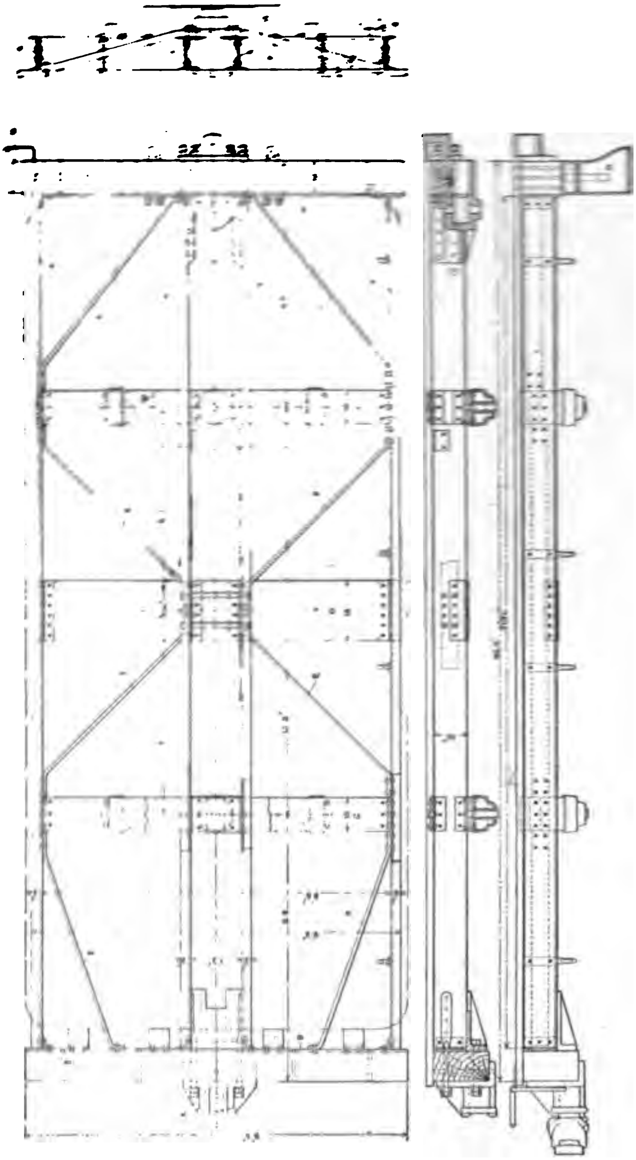


Fig. 67.

the form are used: The sloping back A of the fuel space is sometimes made vertical. The horizontal back end of the tank is sometimes made sloping in the case of switching locomotives, as in Fig. 25, in order to permit the engineer to see the tracks close to the engine, when running backwards.

Tanks are now made of steel throughout, the plates being about ¼ inch thick. It is necessary that they should be substantially constructed in order that they may withstand the shocks due to the surging of the contained water as well as those caused by the movements of the trains. Stiffness is obtained by the use of angle and T-shaped braces and tie-rods as shown at B B.

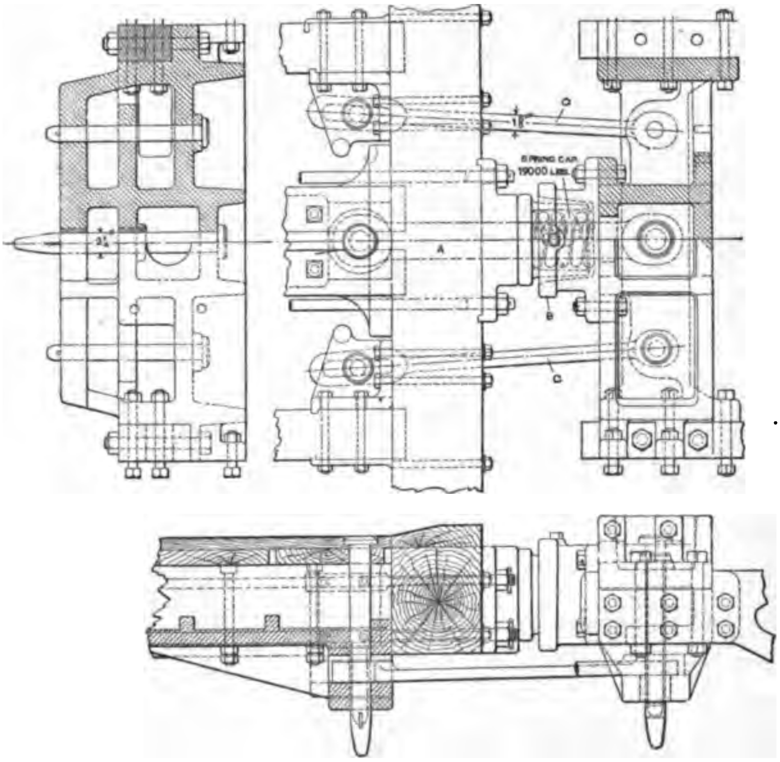


Fig. 68.

Water is admitted through the opening C. A tool box may be placed at D for the reception of spare links and pins, and for derailing frogs, jacks and other tools that are carried on the locomotive. Tool boxes for small tools and signals are also usually placed at the front end on the top of each water leg. The coal is held in position by gates or boards dropped into the groove

E formed by two angles. The outer face of the tank is extended

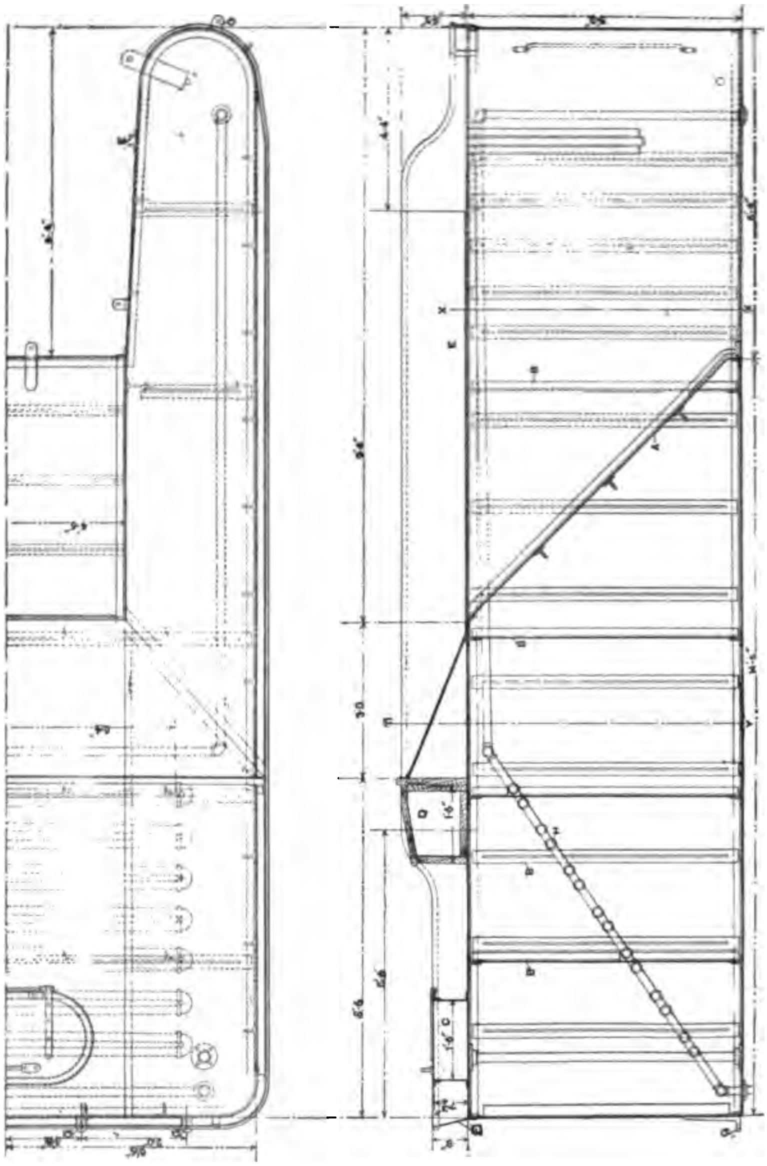


Fig. 60.

upward by the addition of a flare from 8 inches to 12 inches high, by which articles carried on the back end of the tank are prevented from falling off, and by which the coal-carrying capacity is also greatly increased.

Tanks used on northern railroads are also provided with steam pipes H by which the water can be warmed in cold weather so as to prevent freezing. This heater consists of a coil of 1½ inch iron gas pipe by which steam is taken in from a valve in the cab. Sometimes this coil is connected with the safety valve so that all steam escaping therefrom is utilized in warming the water.

Great care must be taken that the tank is firmly secured to the frame. This is done by means of bolts passing through the lugs G G. Unless this is done the tank with its contents will be shifted under the influence of the shocks to which it will be subjected.

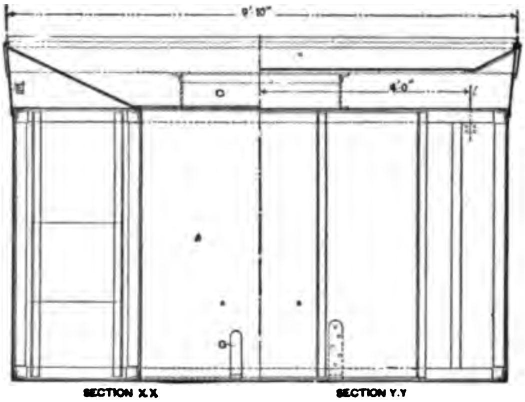


Fig. 70.

The capacities of tanks are varied according to the size of the locomotive and the service which it is to be called upon to perform. The rating of tanks is in gallons of water and tons of coal, For switching engines and engines engaged in short passenger runs the tanks may be comparatively small. Tanks of 2,000 gallons capacity are frequently used for the latter service and even smaller ones for the former. For long passenger and heavy freight runs, tanks are made with capacities of 6,000 gallons and more.

In determining the capacity of a tank to be used in connection with a locomotive the work to be done must be considered

This consists first in a determination of the speed at which the train is to be run, the weight of the train, the size of the cylinders that are to do the work, the grades that are to be overcome, and the distances between points where the tanks can be refilled with water. The nearer these points are together the smaller may be the tank. No definite rule can be made for a calculation on the subject and experience is better than mathematics. However, an approximation can be made in a preliminary calculation.

For the ordinary high-speed express passenger locomotive a water consumption of 35 pounds per horsepower per hour, may be taken as an average.

Suppose then, a train weighing, with the locomotive, 250 tons is to be run for a distance of 50 miles at an average speed of 60 miles an hour. From the formula

$$R = \frac{V}{4} + 2$$

we have a train resistance of 17 pounds per ton or a total of 4250 pounds. The speed is 5,280 feet per minute, hence the horsepower developed is

$$\text{H. P.} = \frac{5280 \times 4250}{33000} = 680$$

To this 25 per cent. should be added for the difference between effective and indicated horsepower making the latter 850 H. P.

In one hour, then, there would be used 850 × 35 = 29,750 pounds of water, and in fifty minutes 24,791⅔ pounds. As a gallon weighs about 8.33 pounds the consumption would be 3,000 gallons (nearly). This is for a straight and level track. An adverse grade of one quarter of one per cent. for half the distance would add about 25 per cent. to the horsepower for half the time, which would call for an additional water consumption of nearly 400 gallons which on an ordinary road would have to be doubled for curves making a total of about 3800 gallons. As there must always be an ample reserve for such a service, the tank should have a capacity of about 5,000 gallons to allow for emergencies and errors of calculation.

The rate of 35 pounds of water per horsepower may be greatly exceeded and other allowance should be made amounting, in all, to at least 25 per cent. above the calculated amount.

In the matter of coal consumption a fair working allowance will be on a basis of 7 pounds of water evaporated per pound of coal. In the above case the 5,000 gallons of water would require 5,735 pounds of coal for which a space for three tons must be provided. If the engine is to make a round trip with one coaling, the tender must have a capacity for 6 tons. For this 45 cubic feet to the ton must be allowed or 270 cubic feet of coal space.

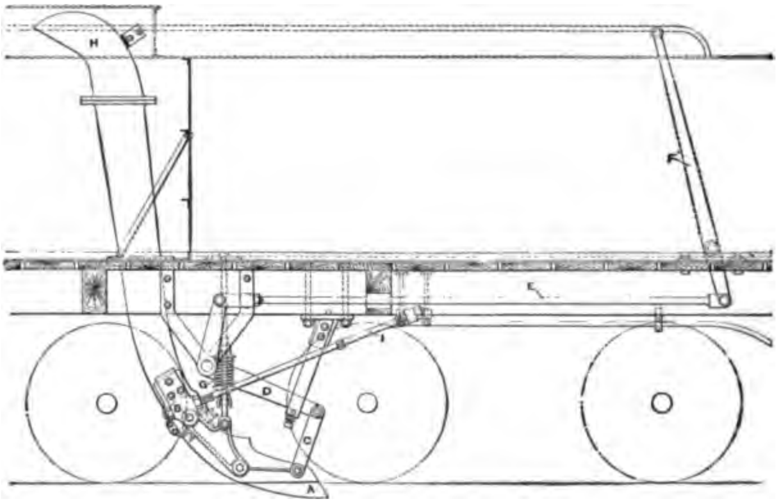


Fig. 71.

Runs greatly exceeding 50 miles without stop can only be done on roads provided with track tanks for taking water into the tender while the train is in motion. This is accomplished by means of a tank placed in the center of the track. This tank is usually made from 6 inches to 8 inches deep and 1,800 feet long. When the tender is over the tank a scoop is lowered into the water and the latter is caught and by its own inertia is forced up into the tank of the tender.

Such a scoop is shown in Fig. 71, where it is shown lowered into the track tank.

In this design the scoop A is pivoted at B to the bottom of the delivery pipe and is raised and lowered by means of the series of levers C, D, E and F. The downward thrust upon the lip of A, when the scoop is moving through the water is balanced by the springs G. The back thrust of the water against the lower end of the delivery pipe is sustained by the rods I.

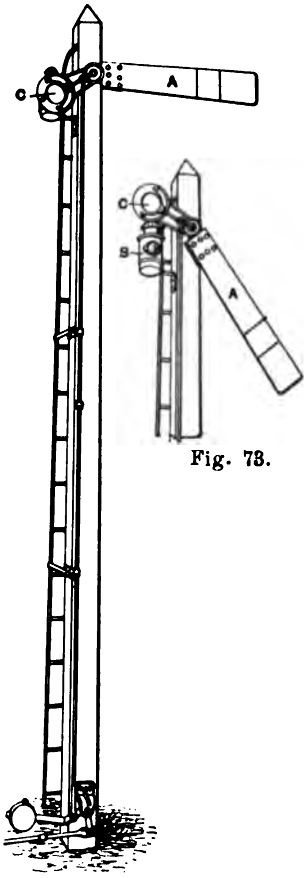


Fig. 72.

Fig. 73.

The manipulation of the scoop is simple. As soon as the tender is over the track tank it is lowered into the position shown in Fig. 71. When the tender tank is filled, or just before reaching the end of the tank the fireman throws the lever F into the forward position raising the scoop clear of the track and rails. Should the fireman be slow in doing this no harm would result, since the ends of the track tank are given a gentle slope upward from the inside.

The amount of water delivered to the tender varies with the speed of the locomotive. It is quite possible to put 3,000 gallons of water into the tender in a distance of 2,000 feet. With the latest improved form of scoop it is possible to take water at a speed of forty miles an hour without injury to the apparatus.

Signals. A signal has been defined as "a means of communication by audible or visible signs between two points, according to a preconcerted system." Railroad signals have for their purpose the governing of the movement of trains. They are of various kinds: flags, lanterns, colored lights, semaphores, discs and targets.

Targets are used to indicate the position of a switch. The target may indicate by form or color or both. It usually consists of two plates of thin metal at right angles to each other attached to the switch staff. The setting of the switch from the main line to a siding, for example, turns the staff through a quarter revolution thus exposing one or the other of the discs to view along the track. The discs or targets are usually painted red and white respectively. When the red signal is exposed the switch is set to lead off to the siding. When the white one is exposed the switch is closed and the main line is clear. At night a red and green or red and white light show in place of the target.

Semaphores. The semaphore may now be considered as the standard method of controlling the movements of trains. It consists of an arm A, Fig. 72, pivoted at one end and fastened to the top of a post 30 feet or 40 feet high. When in the horizontal position it indicates danger. When dropped to a position of 65 or 70 degrees below the horizontal as in Fig. 73 it indicates safety.

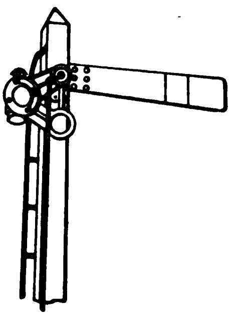


Fig. 74.

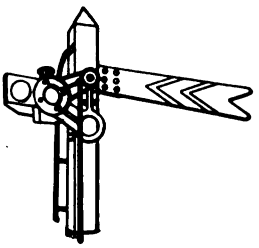


Fig. 75.

At night the semaphore is replaced by a light. There are two systems of light signals. One is to use a red light for danger, a green light for safety, and a yellow light for caution. The other uses red for danger, white for safety and green for caution. The former will probably soon be the standard. The method of operation is to have a lantern B, Fig. 73, attached to the left-hand side of the signal port in such a position that, when the semaphore arm is in the horizontal position, the spectacle glass C will intervene between the approaching engine and the lantern as in Fig. 72. This spectacle glass is red. Where green is to be shown with the semaphore in the position of Fig. 73, the spectacle frame is double, as in Fig. 74. The upper glass being red and the lower green.

Semaphore arms are of two shapes: square at the ends as in Figs. 72 to 74 and with a notched end as in Fig. 75. The square

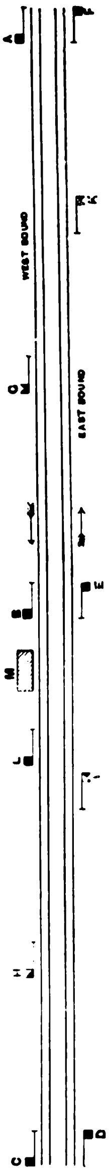


Fig. 76.

ended semaphore is used for what is known as the *home* and *advance* signals and the notched end for *distant* signals.

Semaphores are set so as to be pivoted at the left hand end as viewed from an approaching train. The arm itself extends out to the right.

The use of home, distance and advance signals is as follows: The railroad is divided into blocks at each end of which a home signal is located. When the home signal is in the horizontal or danger position it signifies that the track between it and the next one in advance is obstructed and that the train must stop at that point.

The distance signal is placed at a suitable distance in front of the home signal, usually from 1,200 feet to 2,000 feet, and serves to notify the engineer of the position of the home signal. Thus, if, when he passes the distant signal, the engineer sees it to be in the horizontal position, he knows that the home signal is in the danger position and he must be prepared to stop at that point, unless it be dropped to safety in the meantime. The distant signal should show the cautionary light signal at night.

The advance signal is used as a supplementary home signal. It is frequently desirable, especially at stations, to permit a train to pass a home signal at danger in order that it may make a station stop, and remain there until the line is cleared. An arrangement of block signals is shown in Fig. 76. There are three home signals, A, B, and C on the west bound track, the distance between them being the length of the block. This distance may vary from 1,000 feet to several miles. D, E and F are the corresponding home signals for the east-bound track. The distance signals, G, H, I and K protect the home signals B, C, E and F respectively. L is the advance signal at the station M for the home signal B.

Thus a train scheduled to stop at M will be allowed to run past the home signal at B, when it is at danger, and stop in front of the advance signal L. When L is lowered to safety the train can move on.

The signals of a block are usually interlocked. That is to say, one signal cannot be moved to danger or safety until others have been moved. The signals of two succeeding stations are also interlocked, usually electrically.

The following interlocking principles have been established:

"1. Each home signal lever, in that position which corresponds to the clear signal, must lock the operating levers of all switches and switch locks, which, by being moved during the passage of a train, running according to that signal, might either: *a*, throw it from the track; *b*, divert it from its intended course; or, *c*, allow another train (moving in either direction) to come into collision with it.

"2. Each lever so locked must, in one of its two positions, lock the original home signal in its danger position; that position of lever being taken which gives a position of switch, or switch lock, contrary to the route implied by the home signal when clear.

"3. Each home signal should be so interlocked with the lever of its distant signal that it will be impossible to clear the distant signal until the home signal is cleared.

"4. Switch and lock levers should be so interlocked that crossings of continuous tracks cannot occur, where such crossings are dependent upon the mutual position of switches.

"5. Switch levers and their lock levers should be so interlocked that the lever operating a switch cannot be moved while that switch is locked."

The levers at one signal station are locked from the station in advance. Thus the signal A cannot be put to clear until freed by the operator at B. B cannot be cleared until freed by C, etc.

Levers and signals may be operated by hand, pneumatic or electric power, the last two either automatically or by an operator.

Hall Signal. The disc signals are also used for block signaling. These are usually automatic. The Hall signal, Fig. 77, is an example of this kind. It consists of a closed case A, containing electric apparatus operated by a current controlled by the passage of a train. When the block is closed a red disc fills the

opening B by day, and a red light shows at C by night. A clear signal is indicated by a clear opening at B by day and a white light at C by night.

Where a single track is to be operated by block signals it is customary to put two semaphores on one pole as in Fig. 78. The arm extending to the right, as seen from an approaching train, is the one controlling the movement of that train.

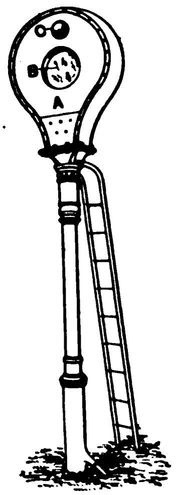


Fig. 77.

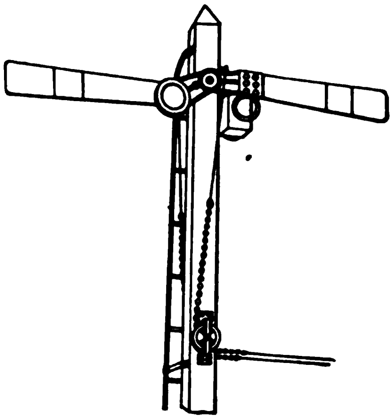


Fig. 78.

Dwarf Signals are in all respects similar to the regular semaphores except in size. They are usually short arms painted red, standing 2 feet to 4 feet from the ground. They are similar to the home signal. They are used only to "govern movements on secondary tracks or movements against the current of traffic on main tracks when such reverse movement becomes necessary, and where necessary in yards." They are especially used for governing the movement of trains in backing out of the train shed at terminals.

Absolute and Permissive Block Signalling. Block signalling should always be *absolute*. That is, when the home signal is at danger, no train should be allowed to pass. It should never be cleared until the whole block in advance is empty. That is, the signal at B, Fig. 76, should never be set to clear until the last preceding train has passed the home signal at C.

Permissive signalling is practiced by many roads. It introduces a time element into the system. Thus when a certain time (from five to ten minutes) has elapsed after a train has passed a home signal, a following train is allowed to proceed, though the signal still remains at danger. The following train is notified of the occupancy of the block by the preceding train, by the display of a cautionary signal (usually a green flag or light) from the tower at the signal so passed. It is a dangerous system and one subversive of good discipline and safety.

Hand Signals are used to govern the movement of trains in switching and other services where the fixed signals previously described cannot be used. They are made with flags, lanterns, torpedos, fusees and by hand. The following signals have been adopted as a standard code by the American Railway Association.

Flags of the proper color must be used by day and lamps of the proper color by night, or whenever from fog or other cause the day signals cannot be clearly seen.

Red signifies *danger* and is a signal to stop.

Green signifies *caution* and is a signal to go slowly.

White signifies safety and is a signal to go on.

Green and white is a signal to be used to stop trains at flag stations for passengers or freight.

Blue is a signal to be used by car inspectors and repairers, and signifies that the train or cars so protected must not be moved.

An explosive cap or torpedo placed on the top of the rail is a signal to be used in *addition* to the regular signals.

The explosion of *one* torpedo is a signal to *stop* immediately; the explosion of *two* torpedoes is a signal to *reduce speed* immediately, and look out for danger signal.

A fusee is an *extra* danger signal, to be lighted and placed on the track at night, in cases of accident or emergency.

A train finding a fusee burning upon the track must come to stop and not proceed until it is burned out.

A flag or lamp swung across the track, a hat or any object waved violently by any person on the track, signifies danger and is a signal to stop.

The hand or lamp raised and lowered vertically is the signal to move ahead (Fig. 79).

The hand or lamp swung across the track is a signal to stop (Fig. 80).

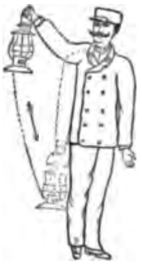


Fig. 79.

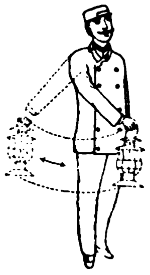


Fig. 80.

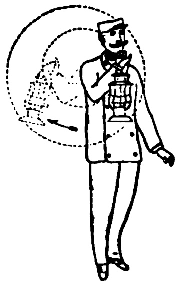


Fig. 81.

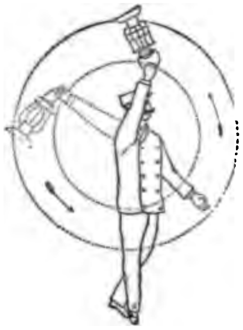


Fig. 82.

The hand or lamp swung vertically in a circle across the track when the train is *standing* is the signal to move back (Fig. 81).

The hand or lamp swung vertically in a circle at arm's length across the track when the train is *running* is the signal that the train has parted (Fig. 82).

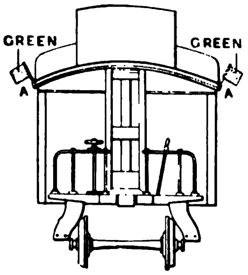


Fig 83.

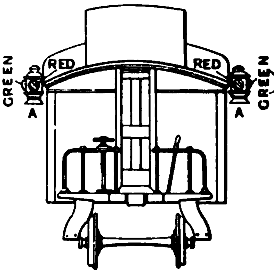


Fig. 84.

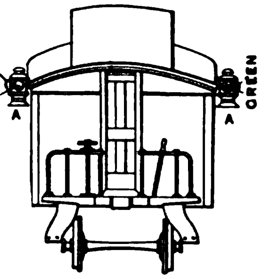
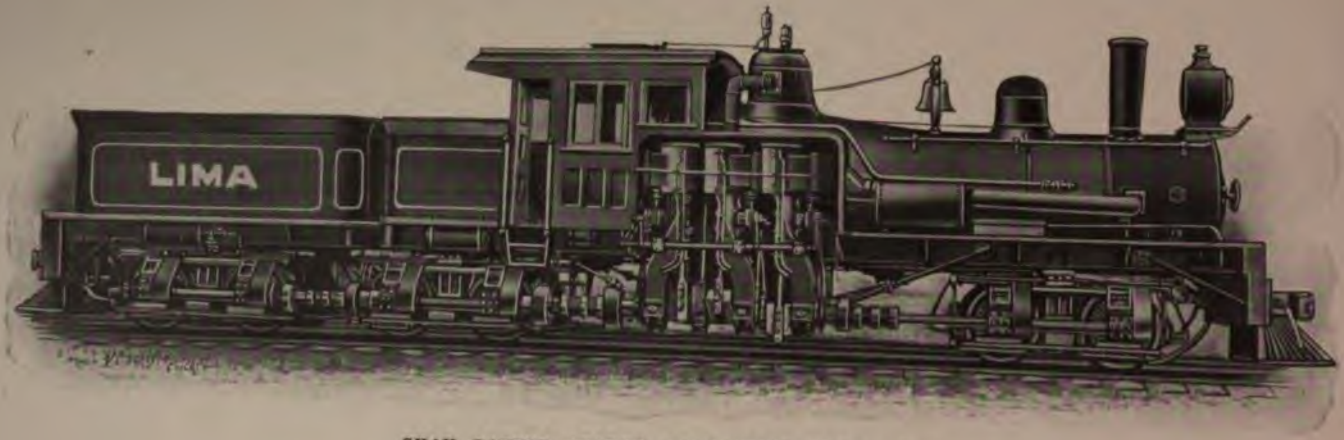


Fig. 85.

Train Signals. Each train, while running, must display two green flags by day (Fig. 83) and two green lights by night, one on each side of the rear of the train, as *markers*, to indicate the rear of the train.

Each train running after sunset or when obscured by fog or other cause, must display the headlight in front, and two or more red lights in the rear (Fig. 84). Yard engines must display two



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green lights instead of red, except when provided with a headlight on both front and rear.

When a train turns out to pass or meet another train, the red lights must be removed and green displayed as soon as the track is clear (Fig. 85), but the red must again be displayed before returning to its own track.

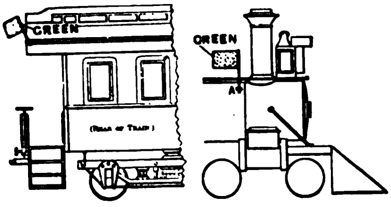

Fig. 86.

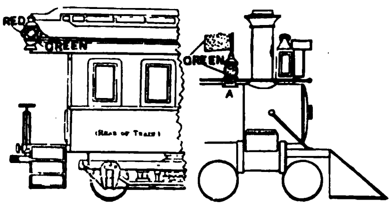

Fig. 87.

Headlights on engines, when on side tracks, must be covered as soon as the track is clear and the train has stopped, and also when standing at the end of a double track.

Two green flags by day and night (Fig. 86), and, in addition, two green lights by night (Fig. 87), displayed in places provided for that purpose on the front of an engine, denote that the train is followed by another train, running on the same schedule and entitled to the same time-table rights as the train carrying the signals.

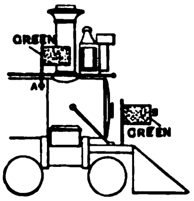

Fig. 88.

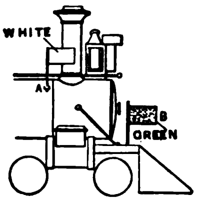

Fig. 89.

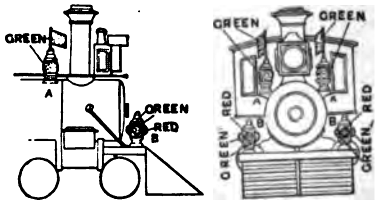

Fig. 90.

Applications of the above rules to locomotives running backward are shown in Figs. 88, 89, and 90.

Fig. 88 shows the arrangement of flags when a locomotive is running backward by day without cars, or pushing cars and carrying signals for a following train. There are two green flags one at A and one at B on each side. The green flag at A is the classification signal, and that at B is the marker denoting rear of train.

Two white flags by day and night (Fig. 91), and, in addition two white lights by night (Fig. 92), displayed in places provided for that purpose on the front of an engine, denote that the train is an extra. These signals must be displayed by all extra trains but not by yard engines.

Fig. 89 shows the arrangement of flags on a locomotive that is running backward by day without cars or pushing cars and running extra. There is a white flag at A and a green one at B.

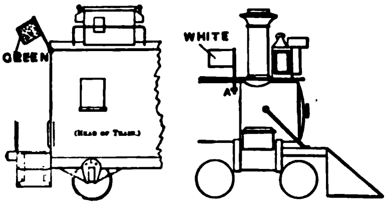

Fig. 91.

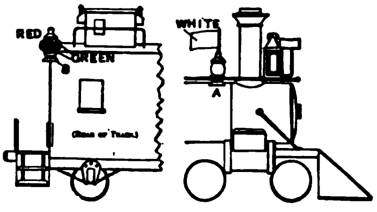

Fig. 92.

The white flag is the classification signal and the green flag is the marker denoting the rear of the train.

Fig. 90 shows the arrangement of flags and lights on a locomotive that is running backward by night without cars or pushing cars and carrying signals for a following train. There is a green flag and light at A and a combination light at B. The green light and flag at A serves as a classification signal. The combination light at B is a marker, showing green on the side and the direction in which the engine is moving, and red in the opposite direction. Fig. 92 shows the arrangement of flags and lights on a train running forward by night and running extra. There is a white flag and white light at A, as a classification signal. At B there is a combination light. This combination light shows green to the sides and front of the train and red to the rear.

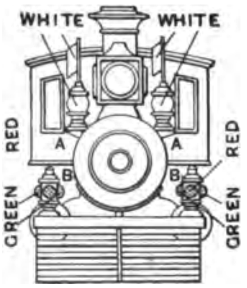

Fig. 93.

Fig. 93 shows the arrangement of flags and lights on a locomotive running backward by night without cars, or pushing cars and running extra. There are white flags and white lights at A A as classification signals. At B B there are combination lights showing green on the sides and in the direction in which the engine is moving, and red in the opposite direction. The combination lights serve as markers.

Fig. 94 shows the arrangement of green marker flags on the rear of the tender of a locomotive that is moving forward by day without cars.

Fig. 95 shows the arrangement of combination lights used as markers on the rear of the tender of a locomotive that is running forward by night without cars. The combination light shows green at the sides and front and red at the back.

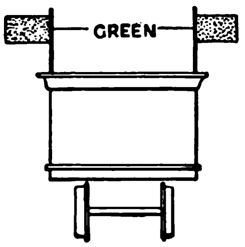

Fig. 94.

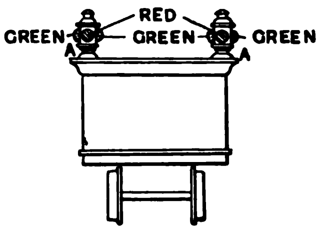

Fig. 95.

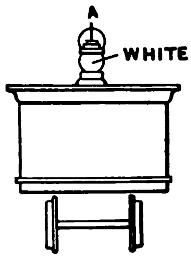

Fig. 96.

Fig. 96 shows the arrangement of lights on the rear of the tender of a locomotive that is running backward by night. There is a single white light at A.

Fig. 97 shows the arrangement of lights on a passenger train that is being pushed by an engine at night. There is a white light A on the front of the leading car.

Fig. 98 shows the arrangement of lights on a freight train that is being pushed by an engine at night. There is a single white light at A.

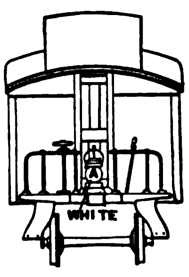

Fig. 97.

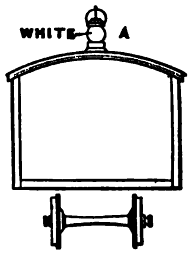

Fig. 98.

Flags. The standard flag used for train signals is 16 inches square.

Whistle Signals. One long blast of the whistle is the signal for approaching stations, railroad crossings and junctions (thus ——).

One *short* blast of the whistle is the signal to apply the brakes to stop (thus —).

Two *long* blasts of the whistle is the signal to throw off the brakes (thus ——— ———).

Two *short* blasts of the whistle is an answer to any signal, except "train parted" (thus, — —).

Three *long* blasts of the whistle to be repeated until answered is a signal that the train has parted (thus ——— ——— ———).

Three *short* blasts of the whistle, when the train is *standing* (to be repeated until answered), is a signal that train will back (thus — — —).

Four *long* blasts of the whistle (thus ——— ——— ——— ———) is a signal to call in a flagman from the west or south.

Four *long* followed by one *short* blast of the whistle (thus ——— ——— ——— ——— —) is the signal to call in a flagman from the east or north.

Four *short* blasts of the whistle is the engineman's call for signals, from switch-tenders, watchmen, trainmen and others (thus — — — —).

Five *short* blasts of the whistle is a signal to the flagmen to go back and protect the rear of the train (thus — — — — —).

One *long* followed by two *short* blasts of the whistle is a signal to be given by trains on single track, when displaying signals for a following train, to call the attention of trains of the same or inferior class to the signals displayed (thus ——— — —).

Two *long*, followed by two *short* blasts of the whistle is the signal for approaching road crossings at grade (thus ——— ——— — —).

A succession of *short* blasts of the whistle is an alarm for persons or cattle on the track, and calls the attention of trainmen to danger ahead.

Bell-Cord Signals. One tap of the signal-bell, when the train is *standing* is the signal to start.

Two taps of the signal-bell, when the train is *running* is the signal to stop at once.

Two taps of the signal-bell, when the train is *standing* is the signal to call in the flagman.

Three taps of the signal-bell, when the train is *running*, is the signal to stop at the next station.

Three taps of the signal-bell, when the train is *standing*, is the signal to back the train.

Four taps of the signal-bell, when the train is *running*, is the signal to reduce speed.

When one tap of the signal-bell is heard while a train is *running*, the engineer must immediately ascertain if the train has parted, and if so, take great precaution to prevent the two parts of the train from coming together in collision.

Signals of the same number of sounds have the same significance when given by other appliances than bell-cord and signal-bells, such as the air whistle described in the section devoted to Air Brakes.

Running. The actual handling of a locomotive upon the road can only be learned by practice with the engine itself, but there are certain principles which must be borne in mind and applied.

Firing. Before taking charge of a locomotive a considerable period must be spent as a fireman. The first things to be learned are the principles governing the combustion of the fuels that are to be burned. For the laws and phenomena of combustion see standard works on "Chemistry."

The lifference between the work of a locomotive boiler furnace and one under a stationary boiler is that in the former the rate of fuel consumption is very much the greater of the two. In locomotive boilers it is common practice to burn 150 pounds of bituminous coal per square foot of grate per hour, while a consumption of 200 pounds per square foot per hour is not infrequent.

Different fuels require different treatment in the firebox.

Wood. The burning of wood is simple. The main thing is to keep the firebox well filled. The box should be deep and the fuel should fill the whole space between the grates and the door and bottom row of tubes. The wood should be cut into lengths not exceeding 16 inches. When thrown into the firebox it should be made to lie all in the same direction and be packed as closely as possible, so as to limit the quantity of air passing through the firebox to that required to effect combustion.

Coke should be burned in very much the same manner as wood. The firebox should be well filled. The stoking with coke had best be done, wherever it is possible, after steam has been shut off or while the engine is standing at stations. The firebox should then be filled. If the bed is not sufficient to last until the next stop, fuel may be thrown on between stations but the bulk of the firing should be done as already indicated. Coke burning locomotives should always be provided with a means for admitting air to the furnace above the fuel. If hollow stays are not provided, the door should always be kept upon the latch. With the deep bed of fuel, sufficient air cannot be admitted through the grates to burn to carbonic acid. Coke fires should be shaken occasionally on the road and be thoroughly cleaned of clinker at each terminal.

Bituminous Coal is the most common fuel used on American locomotives. It varies so much in chemical composition and heating capacity that no fixed rule can be laid down for the burning of it. The work of the fireman varies more or less with each grade of coal. Ordinarily the fuel bed should be comparatively thin. It may vary from six to ten inches and occasionally may be more in thickness, depending upon the work that the locomotive is doing. The bed should be of sufficient thickness to lie upon the grates and not be lifted under the influence of the draft created by the exhaust.

In stoking, the work must be pretty nearly constant. Three shovelfuls at a time is a good average amount. The door should be closed between each shovelful so as to be only open on the latch. This delivers air to complete the combustion of the hydrocarbon gases that are distilled the moment the fresh coal strikes the incandescent fuel. In placing the fuel in the firebox it is well to heap it up in the corners and allow the thinnest portion of the bed to be in the center of the grate. The frequency of the firing depends upon the work that the engine is being called upon to do.

The fire should always be cleaned at terminals and when the grade is favorable the slice bar may be used and the clinker removed through the furnace door while running.

Anthracite Coal requires a treatment intermediate between coke and bituminous coal. Wherever it is possible, it is well to do the stoking on favoring grades and at stations. The thickness of the bed varies with the size and kind of coal used. It varies from 3 inches with the fine pea and buckwheat coal to 10 inches with large lumps. The fuel should be evenly distributed over the whole grate. The upper surface of an anthracite coal fire must never be disturbed by the slice bar while the engine is at work. This should only be done when there will be ample time after its completion to enable the fire to come up again and be burning vigorously before the engine resumes work.

Feeding the Boiler is a matter requiring skill and judgment especially where the locomotive is being worked to its full capacity. The injector is now the universal means employed for boiler feeding. Where it is possible the most satisfactory way is to use a constant feed that will be the average for the trip. In this way the water level will rise and fall but will always be sufficient to cover the crown sheet. Under no circumstances should the water level be allowed to fall below the bottom gauge cock.

Where a constant feed cannot be used, the injector may be worked to its full capacity on favoring grades and at station stops. This will give a storage of water to be drawn from when the engine is working to its full capacity on adverse grades. Under such circumstances the stopping of the feed may enable the fire to maintain the requisite steam pressure, whereas the latter might fall if the injector was to be kept at work. Further, the use of the injector on down grades and at stations keeps down the steam pressure and prevents the loss of heat by the escape of steam through the safety valves, when the fire is burning briskly and the engine is not at work.

Use of Steam. The manner in which an engineer uses the steam in the cylinders is one of the controlling elements in the economical use of coal. In starting, the reverse lever must be thrown forward so that steam is admitted for as long a distance in the stroke of the piston as the design of the link motion will permit. As the speed increases the lever should be drawn back, shortening the cut-off, and it will usually be found that, when the engine is not overloaded, a higher speed will be attained and maintained with a short than with a late cut-off. The reason is that, with the late cut-off or valve closure, so much steam is admitted to the cylinder that it cannot be exhausted in the time allowed. The result is an excessive back pressure that retards the speed.

It is probable, however, that it is not economical to use a cut off that occurs earlier than one-quarter stroke. Where an earlier cut-off is used the increased cylinder condensation is apt to more than off-set the saving effected by the increased expansion so obtained. Hence, when the engine is running under such conditions that a cut-off earlier than one-quarter stroke can be used with a throttle valve wide open, it may be better to keep the point of cut-off at one-quarter stroke and partially close the throttle valve, thus wire-drawing the steam. The wire-drawing of steam serves to superheat it to a certain extent and thus tends to diminish the cylinder condensation that would occur were saturated steam of the same pressure to be used.

When running with the throttle valve closed, the reverse lever should be set to give the maximum travel to the valve. This tends to prevent the wearing of a shoulder on the valve seat.

Learning the Road is one of the most important things for the engineer to accomplish. He must know the road as a pilot knows a river. He must know every grade, curve, crossing, station approach, bridge, signal and whistle or bell post on the division over which he runs. He must know them on dark and stormy nights as well as in daylight. He must always know where he is and never be at the slightest loss as to his surroundings. He must not only know where every water tank is located, but should also make himself familiar with the qualities of the various waters that they contain. Then, when he has a choice of places at which to take water, he may choose that containing the smallest amount of scale-forming matter.

Grades. In the learning of a road, an intimate knowledge of the grades is of the first importance to the engineer. He must know what his engine can haul over them; how it must be handled when on them, and how they must be approached. An engine will frequently be able to take a train over a grade, if it has a high speed at the foot of the same; whereas, if a stop or a slackening of the speed were to be made there, it would be impossible to surmount it with the whole train.

Handling Trains over different profiles of track requires different methods. On adverse grades the work is probably the simplest. In such conditions the train is stretched out to its utmost. Every car is pulling back, and any checking of the movement at the front of the train meets with an immediate response throughout the whole train. The grade also prevents sudden acceleration at the front. It is, therefore, merely necessary to keep the engine at work pulling.

On favoring grades the whole train, when drifting, is crowding down upon the locomotive and is likely to be bunched or closed together. Under these conditions it is necessary to apply the air brakes, which are at the front end, and keep them applied so as to hold the speed under control and prevent the train from running away. Care should be taken about the application of the driving wheel brakes on long down grades, lest the shoes heat the tires and loosen them.

It is in passing over ridges and through sags that the danger of injury to the train arises. First in leaving an adverse grade and passing over a ridge to a favoring grade, the engineer must be careful not to accelerate the front end of the train too rapidly lest it break in two before the rear end has crossed the summit. There is a greater danger, however, in running through a *dip* where the grade changes from a favoring to an adverse one. Where the brakes have been applied at the rear of the train and the slack prevented from running together there is not the same danger that there is when the brakes have been applied at the front of the train and it has been allowed to bunch. In the latter case, if the engineer is not careful in pulling out, the train will be jerked in two. The principle upon which the avoidance of this class of accident is based is that of not allowing the slack to be taken up suddenly. A steady pull will not break the draft rigging of a car when a sudden jerk will pull it out.

In case a train does break in two, the engine and front portion should be kept in motion until the rear has been stopped so as to avoid a collision. Where air brakes are applied to the whole train the rear will stop first owing to the proportional increase of weight and momentum of the locomotive.

Freight trains require, on the whole, more careful handling than passenger trains. There is more slack in the couplings of the former than of the latter, and the trains are much longer. Consequently the shocks at the rear of a freight train, due to variations of speed, are much more severe than on passenger trains. The system of handling, while practically the same for both classes, requires more care, in order to avoid accidents with the freight than with the passenger.

Making Ready. The first step in the preparation of an engine for the road is the filling of the boiler with water to the second gauge and the raising of steam. For the latter several methods are employed. The oldest method is to build a fire of cord wood and when it is well lighted to throw on coal. As soon as pressure shows upon the gauge the blower may be opened to force the fire and clear the cab and round-house of smoke. Fire lighters are also extensively used. These are made of a combination of highly inflamable materials of which resin is an important one, which are placed in the firebox and ignited either beneath or on top of a bed of coal. With the coal ignited the work becomes the same as when wood is used.

Lately various other methods of fire kindling have been used. An apparatus designed for this purpose is shown in Fig. 99. It consists of a tank A slung between a pair of handles and carried on two wheels with connections for forcing out and spraying the contained oil.

In operation the tank is wheeled alongside the engine and the hose B connected to a source of compressed air supply in the round-house. By opening the valve I, the air is allowed to pass down into the tank, creating a pressure on the surface of the contained liquid ; it then follows the direction of the arrow into the hose D. The pressure exerted upon the liquid is indicated by the gauge and can be regulated by the valve I. When the plug cock J is opened the oil is forced up the pipe C and into the hose E. The sprayer H is placed at the ends of two pieces of pipe through which the flow of air and oil is regulated by the valves G and F, respectively.

When the air and valves have been opened the spray of oil issuing from H is ignited and the flame thrust in at the firebox door and down against the bed of coal that has previously been put upon the grates. The nozzle is then moved over the surface until the whole is ignited, an operation that requires about fifteen minutes, after which the raising of steam is carried on in the usual way, except that compressed air is sometimes admitted to the blower to assist the draft.

This work is usually done by the roundhouse men.

The fireman is expected to see to it that all necessary supplies are upon the engine. These include flags, lanterns, oil, and fire irons.

The engineer should see to it that there is ample water in the boiler and that the machinery is well oiled. Careful and deliberate oiling of all parts, with an adjustment of the feeding apparatus of the lubricators should be made before the engine leaves the roundhouse.

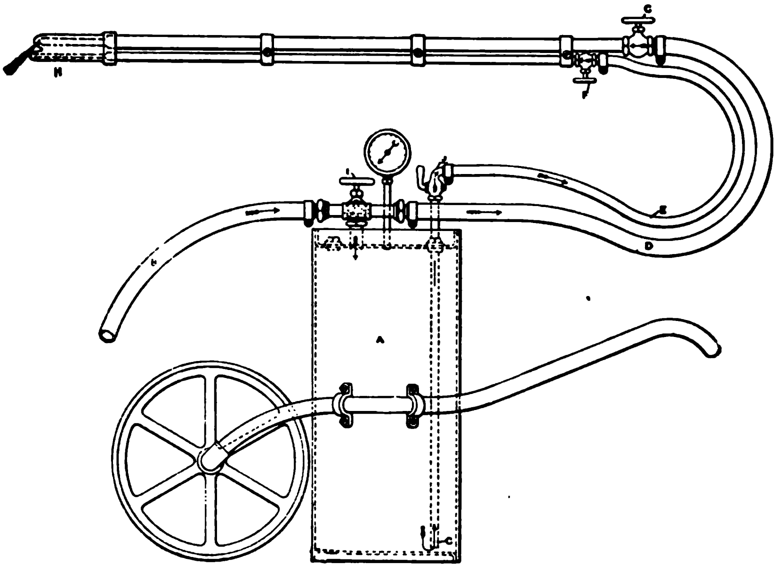

Fig. 99.

End of the Run. When the run has been finished the engineer should make a careful inspection of all parts of the engine so as to report any repairs that may be needed in order to fit it for the next run. The roundhouse hostler then takes the engine to the coaling shute and ashpit, loads the tender with coal, fills its tank with water, and cleans the fire. The engine is then put over a pit in the roundhouse and should be carefully wiped and again inspected for defects.

Inspection. The inspection of locomotives should be thorough in the extreme. It should embrace the condition of every wearing surface that is exposed and the behavior of every one that is concealed. Every bolt and nut should be examined to ascertain that it is tight. The netting in the front end or in the stack should be examined at frequent intervals to make sure that it is whole. The stay-bolts should be inspected periodically in order that those broken may be replaced. Wheels and all parts of the running gear and mechanism should be carefully scrutinized for cracks or other defects.

Cleaning should be done after every trip since dirt is apt to cover defects that may be serious and the cause of a disaster.

Repairs of a minor nature can be made in the roundhouse and should be promptly attended to. Roundhouse repairs include such work as the replacing of worn netting, the cleaning of nozzles, the expanding and caulking of leaking tubes, the refitting of side and connecting rod brasses, the re-facing of valve seats, the regrinding of the cab fittings that become leaky, the adjustment of driver box wedges, repairs to ashpans, replacing of grates, renewal of brake-shoes, re-setting of valves, light tank repairs, and sometimes even extends to the re-boring of cylinders. To this must be added the regular work of renewal of all packing and the periodical washing out of the boiler.

Emergencies are constantly arising in locomotive running where a breakage of some part should be repaired upon the road. The part effected and the extent of the fracture has much to do with the possibility of running the engine home under its own steam. A few methods of dealing with breakage will be given.

Broken Side-Rod. If a side rod breaks, the ends should be disconnected and the rod on the opposite side of the engine should also be removed. Never attempt to run a locomotive with only one side rod connected.

Broken Connecting-Rod. If a connecting-rod is broken without injury to the cylinder, the crosshead and piston should be blocked at one end of the stroke and the broken parts of the rod removed. The removal of the side rods depends upon the extent of injury of the crank-pin, on the broken side. The valve-rod should be disconnected from the rocker arm and the valve-stem clamped with the valve in the central position. The valve-stem may be clamped by screwing down one of the gland nuts harder than the other, thus cramping the stem, and also by the use of the clamp shown in Fig. 100. This consists of two clamps having V-shaped notches that are securely fastened to the valve-stem by a bolt on either side. This is done after passing the gland studs through the two slotted holes, whereby any longitudinal movement of the stem is prevented by screwing down the nuts on the studs. The crosshead should be forced to one end of the guides with the piston hard against one cylinder head. It can be held in this position by a piece of plank sawn to fit snugly between it and the guide yoke.

When the parts on one side have been blocked in this way the engine can be run to the shop with one side working.

Broken Driving Springs. In case of breakage of these parts, a block of wood should be inserted between the top of the driving box and the frame. This can be done by first removing the broken spring and its saddle and then running the other drivers on wedges to lift the weight off that one where the spring is broken. Insert the piece of wood and then run that pair of drivers up on wedges. Then pry up the fallen end of the equalizer until it is level and block in that position. Always remove all parts that are liable to fall off.

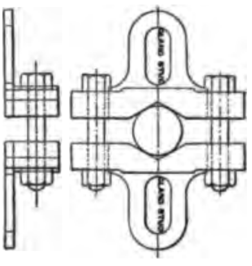

Fig. 100.

Low Water. If, for any reason, water gets low in the boiler, or if, through an accident, some of the heating surface is laid bare, the fire should be dampened. This can best be done by throwing dirt into the firebox. Never turn in a stream of water.

Foaming. If foaming occurs, the throttle should be closed slowly. This keeps the water from dropping suddenly and uncovering the crownsheet. If there is a surface blow-off, open it and allow the impurities on the surface of the water to be carried away. If the foaming in caused by grease, allow the tank to be overflowed at the next water station and put a couple of quarts of unslaked lime in the water. If this is not obtainable put a piece of blue vitriol in the hose, back of the screen. This may be obtained at almost any telegraph office.

Broken Steam Chest. In this case the lower joint of the steam pipe on the side of the accident should be pried apart and a wooden gasket inserted. Or the steam chest and valve may be removed and a piece of board laid over the steam openings. This board can be firmly clamped in position by the studs of the steam chest.

These are a few of the accidents that may occur on the road. To prepare for emergencies the best method is to study the locomotive and devise means of making temporary repairs for every accident that can be imagined. Then, when the accident does occur, the remedy can be promptly applied.

Train Rules. The American Railway Association has adopted a uniform code of train rules for the railroads of the United States. These rules provide that:

All trains are designated as regular or extra and may consist of one or more sections. An engine without cars, in service on the road, is considered a train.

All trains are classified with regard to their priority of right to the track.

A train of an inferior class must, in all cases, keep out of the way of a train of a superior class.

On a single track all trains in one direction specified in the time table, have the absolute right of track over trains of the same class running in the opposite direction.

When trains of the same class meet on a single track, the train not having the right of track must take the siding and be clear of the main track before the leaving of the opposing train.

When a train of inferior class meets a train of superior class on a single track, the train of inferior class must take the siding and clear the train of superior class, five minutes.

A train must not leave a station to follow a passenger train until five minutes after the departure of such passenger train, unless some form of block signal is used.

Freight trains following each other must keep not less than five minutes apart unless some form of block signal is used.

No train must arrive at or leave a station in advance of its schedule time.

When a passenger train is detained at any of its usual stops more than —— minutes, the flagman must go back with danger signal and protect his train, but if it stops at any unusual point, the flagman must immediately go back far enough to be seen from a train moving in the same direction when it is at least —— feet from the rear of his own train.

When it is necessary to protect the front of the train, the same precautions must be observed by the fireman. If the fireman is unable to leave the engine, the front brakeman must be sent in his place.

When a freight train is detained at any of its usual stops more than —— minutes, where the rear of the train can be plainly seen from a train moving in the same direction at a distance of at least —— feet, the flagman must go back with danger signals not less than —— feet and as much farther as may be necessary to protect his train ; but if the rear of his train cannot be plainly seen at a distance of at least —— feet, or if it stops at any point that is not its usual stopping place, the flagman must go back not less than —— feet, and if his train should be detained until within ten minutes of the time of a passenger train moving in the same direction, he must be governed by Rule No. 99.

Rule 99 provides that when a train is stopped by an accident or obstruction the flagman must immediately go back with danger signals to stop any train moving in the same direction. At a point —— feet from the rear of his train he must place one torpedo on the rail ; he must then continue to go back at least —— feet from the rear of his train and place two torpedoes on the rail ten yards apart (one rail length), when he may return to a point —— feet from the rear of his train, and he must remain there until recalled by the whistle of his engine ; but if a passenger train is due within ten minutes, he must remain until it arrives. When he comes in, he will remove the torpedo nearest to the train, but the two torpedoes must be left on the rail as a caution signal to any following train.

When it is necessary for a freight train on a double track to turn out on to the opposite track to allow a passenger train running in the same direction to pass, and a passenger train running in the opposite direction is due, a flagman must be sent back with a danger signal, as provided in Rule No. 99, not less than —— feet in the direction of the following train and the freight train must not cross over until one of the passenger trains arrives. Should the following passenger train arrive first, a flagman must be sent forward on the opposite track with danger signals, as provided in Rule No. 99, not less than —— feet in the direction of the over-due passenger train before crossing over. Great caution must be used, and good judgment is required to prevent detention to either passenger train. The preference should always be given to the passenger train of superior class.

If a train should part while in motion, trainmen must use great care to prevent the detached parts from coming into collision.

Regular trains twelve hours or more behind their schedule time lose all their rights.

All messages or orders respecting the movement of trains or the condition of track or bridges must be in writing.

Passenger trains must not display signals for a following train without an order from the superintendent; nor freight trains without an order from the yard master.

Great care must be exercised by the trainmen of a train approaching a station where any train is receiving or discharging passengers.

Enginemen must observe trains on the opposite track, and if they are running too closely together, call attention to the fact.

No person will be permitted to ride on an engine except the engineman, fireman and other designated employes, in the discharge of their duties, without a written order from the proper authority.

Accidents, detention of trains, failure in the supply of water or fuel, or defects in the tracks or bridges, must be promptly reported by telegraph to the superintendent.

No train shall leave a station without a signal from its conductor.

Conductors and enginemen will be held equally responsible for the violation of any rules governing the safety of their trains,

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sheet of standard specifications for a consolidation locomotive which is used as a part of the contract made by a railroad with a locomotive builder:

A Simple Consolidation Locomotive Engine, having 4 pairs of coupled wheels and a 2-wheeled swinging truck for the New York, Paris & Pekin R. R. Company.

General Description. General design illustrated by attached photograph of engine No. 59.

Cylinders 21 inches diameter and 26 inches stroke.

Driving-wheels 56 inches diameter. Gauge 4 feet 8½ inches. Fuel, coal. Total Wheelbase 23 feet 6 inches. Driving Wheelbase 15 feet 5 inches.

Weight in working order, total about 156,000 pounds; on driving-wheels, about 140,000 pounds.

Weight of tender, with fuel and water, about 85,000 pounds.

Boilers to be made throughout of flange plates of homogeneous steel, American Railway Master Mechanics' specifications, $\frac{11}{16}$ and $\frac{3}{4}$ inch thick; all longitudinal seams butt jointed with double covering strips. Throat sheet thicker than shell of boiler, to prevent undue thinning where flanged. All parts well and thoroughly stayed, with liners on inside of side sheets, providing double thickness of metal for studs of expansion braces. All plates planed at edges and calked with round-pointed calking-tool, insuring plates against injury by chipping and calking with sharp-edged tools. Boiler tested with steam to at least 20 pounds above working pressure, and with hot water to 40 pounds pressure per square inch above the working pressure. Working pressure 180 pounds.

Waist 64 inches in diameter at smoke-box end; made extension wagon top and with one dome placed on extended wagon top.

Tubes of charcoal iron or cold drawn steel. No. 12 Birmingham wire-gauge with copper ferrules on swaged ends in fire-box tube-sheet, 298 in number, 2 inches in diameter, and 13 feet 6 inches in length.

Fire-box 108 inches long and 41½ inches wide; inside of fire-box flange steel, all plates thoroughly annealed after flanging; inside and back sheets $\frac{3}{8}$ inch thick. Crown sheet $\frac{3}{8}$ inch thick;

and they must take every precaution for the protection of their trains, even if not provided for by the rules.

In all cases of doubt or uncertainty take the safe course and run no risks.

Time-tables. A time-table is the general law governing the arriving and leaving time of all regular trains at all stations. Time-tables are issued from time to time, as may be necessary. The times given for each train on the time-table is the schedule of such train.

Each time-table, from the moment it takes effect, supersedes the preceding time-table, and all special instructions relating thereto; and trains shall be run as directed thereby, subject to the rules. All regular trains on the road running according to the preceding time-table shall, unless otherwise directed, assume the times and rights of trains of corresponding numbers on the new time-table.

Upon the time-table not more than two sets of figures are shown for a train at any point. When two times are shown, the earlier is the arriving time and the later the leaving time. When one time is shown it is the leaving time unless otherwise indicated.

Regular meeting or passing points are indicated on the time-table by figures in full-faced type.

Both the arriving and leaving time of a train are in full-face type when both are meeting or passing times, or when one or more other trains are to meet or pass it between those times.

On the employes' time-table the words "daily," "daily, except Sunday," etc., printed at the head and foot of a column in connection with a train, indicate how it shall be run. The figures given at intermediate stations shall not be taken as indicating that a train will stop unless the rules require it. The following signs placed before the figures indicate:

"s" regular stop.

"f" stop on signal to receive or discharge passengers or freight.

"¶" stop for meals.

Trains are designated by numbers and their class indicated on the time-tables.

Locomotive Specifications. The following is a copy of a nected to steam chests by copper pipes running under the jacket. Pipes proved to 200 pounds pressure.

Pistons of cast iron, fitted with approved form of steam packing. Piston-rods of hammered iron or steel, ground and keyed to crossheads and securely fastened to pistons.

Metallic packing for piston-rods and valve-stems.

Guides of steel, cast iron or wrought iron, case-hardened, fitted to wrought-iron guide yoke.

Crossheads of cast steel with suitable bearings.

Shifting-link motion, graduated to cut off equally at all points of stroke. Links, sliding blocks, pins, lifting links, and eccentric-rod jaws made of hammered iron, well case-hardened. Sliding blocks with long flanges to give ample wearing surface. Rock shaft of wrought iron; reverse shaft of wrought iron. Slide valves cast iron balanced pattern.

Eccentric straps of cast iron.

Driving-wheels eight in number; 56 inches in diameter. Centers of cast iron turned to 50 inches diameter.

Crank-pins of hammered open hearth steel.

Tires of cast steel 3 inches thick when finished; two pairs flanged 5½ inches wide; two pairs plain 6½ inches wide.

Axles of hammered iron or open hearth steel; journals 8 inches diameter and 10 inches long.

Driving-boxes of cast iron with phospher bronze bearings.

Springs of crucible cast steel, tempered in oil.

Equalizing beams of wrought iron.

Connecting and parallel rods of steel or hammered iron. Connecting-rods, one section forged solid, and furnished with all necessary straps, keys and brasses. Parallel rods, one section solid ends and heavy bushings. Bushings put in by hydraulic press, and well secured from turning in the rod. Lubrication of all bearings carefully provided for, and oil cups attached where required. Wick or adjustable needle oil cups on rods and guides.

Wrist pins of steel or wrought iron.

Feed water supplied by two No. 10 injectors.

Accessories. Cab substantially built of clear, sound ash, or clear pine, well finished, and fitted together with joint bolts and corner plates. To be provided with suitable windows and doors, conveniently arranged, and glazed with first-quality double American crystal glass.

Pilot of wood braced with iron and having master car builders coupler.

Engine to be finished with one sand-box and an automatic sander, stand for head-lamp, bell, plain or chime whistle, blow-oft cock, blower and 3½ inch open and 3½ inch muffled American safety-valves, 6¾ inch steam guage, cab lamp, gauge cocks; also a complete set of tools, consisting of two heavy jack-screws and levers, one heavy pinch-bar with steel point and heel, complete set of wrenches to fit all nuts and bolts on engine, including two monkey-wrenches, one set of driving box packing tools, one machinist's hammer, one soft hammer, three cold chisels (two flat and one cape), one long spout quart oil-can, one two-gallon oil-can, one tallow-pot, one torch, engineer's arm-rest, one extra fusible plug, one bell-cord, cab-seats, cab-seat cushions, one poker, one scraper, one slice-bar and one scoop shovel.

Headlights to be 16 inches diameter with round case.

Brakes to be Westinghouse American outside equalized on drivers and tender, and 9½ inch pump.

Automatic bell ringer.

Cylinders lagged with wood and neatly cased with iron, painted. Cylinder-head covers of cast iron, painted or polished. Steam-chests with cast iron tops; bodies cased with iron, painted. Boiler lagged with asbestos, jacketed and secured by plainished iron bands. Dome lagged with same material as boiler, with painted iron casing on body and cast iron top and bottom rings. Hand rails of iron. Running-boards of wood with nosings of iron. Wheel-cover nosings of iron. Engine and tender to be well painted and varnished. Lettering and numbering to be as specified by purchaser.

General Features of Construction. All principal parts of engine accurately fitted to gauges and templates, and thoroughly interchangeable. All finished movable nuts and all wearing surfaces of valve motion made of steel, or iron case-hardened. All wearing brasses made of phosphor bronze or ingot copper and tin. alloyed in proportion to give best mixture for wearing bearings. All threads on bolts of United States standard.

Tender. Tank of steel strongly put together, with angle-iron corners and well braced. Top inside, and bottom plate $\frac{1}{4}$ inch thick; outside plates $\frac{3}{16}$ inch thick; riveted with $\frac{3}{8}$ inch rivets, $1\frac{1}{4}$ inch pitch; capacity 4,000 gallons (of 231 cubic inches). Tender frames substantially built of channel steel strongly braced. Two four-wheel center-bearing trucks; made with wrought iron side-bars and cross-beams of wood or channel iron; additional bearings at sides of back truck. Springs, crucible cast steel, tempered in oil. Eight double-plate chilled wheels 33 inches diameter. Brakes on both trucks.

Axles of hammered iron or open hearth steel, outside journals $4\frac{1}{4}$ inches diameter and 8 inches long. Oil-tight boxes with brass or bronze bearings.

Tool boxes of hard wood fitted with locks and keys.

Then follows the detail of the specifications for the boiler and fire-box steel according to those already outlined on pages 10 and 11 of Part I.

These specifications cover the thickness of the plates, test strips, marking homogenity tests, bending test, tensile strength, elongation in eight-inch section, chemical composition, specifications for boiler tubes and safe ends, bar iron and its physical requirements, specifications for stay-bolt iron and its physical requirements, for phosphor bronze bearing metal, for steel castings and their physical requirements, also for cast iron, steel billets for rods, axles, piston-rods, guides, crank-pins, and finally for tank steel and engine bolt iron.

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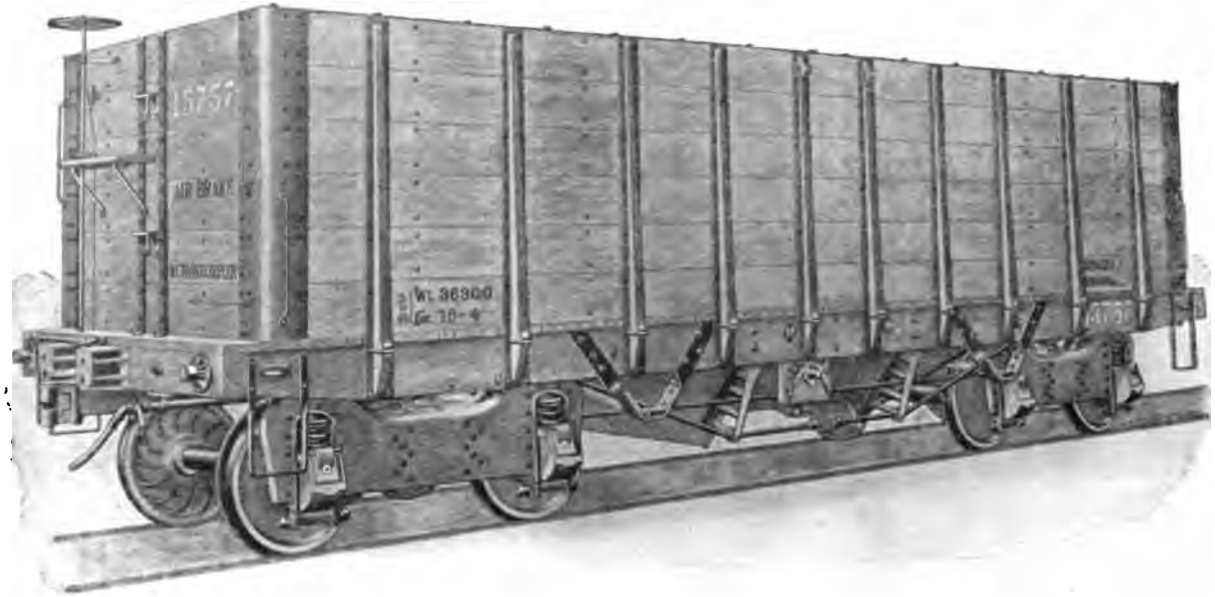


MODERN AMERICAN HOPPER-BOTTOM GONDOLA CAR, WITH AIR BRAKE EQUIPMENT.

THE AIR BRAKE.

Brakes are used upon railway trains for the purpose of reducing their speed and stopping them. The speed would be reduced, however, and the train would stop if no brakes were applied. Such a stop would be the result of the resistance of the journal friction and of the atmosphere. Brakes are used to stop the train more quickly than could be accomplished by journal friction and air resistance. Brakes are usually applied in the form of a shoe which presses against the tread of the wheel. In special cases a brake shoe is pressed against the rail. These forms however, are so seldom used that they need not be considered. When brake shoes are pressed against the tread of a rolling wheel, a frictional resistance is set up that tends to retard the movement of the wheel and, consequently of the the vehicle which it carries. The amount of this retardation depends upon three factors: The materials of which the wheel and the brake shoe are composed, the weight of the car, and the pressure of the shoe against the wheel. The first item determines the coefficient of friction. The coefficient of friction is the ratio of the resistance which the brake shoe offers to the movement of the wheel, to the pressure of the shoe upon the wheel. Thus the coefficient of friction of a cast iron shoe on a steel tired wheel may be .16. That is to say, if a shoe is pressed against a wheel with a pressure of 5,000 pounds it has the same retarding effect as a pull of 5,000 × .16 = 800 pounds at the rear of the car. As there are eight wheels on each car, and, as the brakes are applied with equal force to each wheel the total retarding force for the whole car would be 800 × 8 = 6,400 pounds. Hence, with the brakes applied in this way, the car must do the work of lifting 6,400 pounds one foot for each foot of its own motion. At a speed of 40 miles per hour or 3,520 feet per minute, the brakes are doing 3,520 × 6,400 = 22,528,000 foot pounds of work per minute in checking the motion of the car.

It has been found by experiment that, in ordinary working, only 70 per cent. of the weight on the wheel can be applied to it in brake shoe pressure without skidding. This is due to the fact that the coefficient of friction between the wheel and the rail is less than between the wheel and the shoe. It has also been found experimentally that the greatest retardation occurs when the wheel is just on the point of slipping but is nevertheless rolling with the full velocity of the car. The objection to skidding is that flat spots will wear on the tread of the wheel because of this action.

The operation of a brake upon a railroad car is similar to the action of gravity. The difference lies in the intensity of the force. Gravity acts with a force equal to the weight of a body. The brakes act with but a small percentage of that weight. The retarding force of the brakes is found by multiplying the percentage of the brake pressure to the weight on the wheels by the coefficient of friction. Thus, suppose the brake shoe pressure is equal to 70 per cent. of the weight of the car, and that the coefficient of friction is .16. Then the retarding force is equal to $.70 \times .16 = .112$ of the weight of the car.

If we know the vertical velocity of a body, we can calculate the height to which it will rise from the earth when retarded by gravity. Suppose, then, a body to have a vertical velocity of 40 miles per hour at the surface of the earth. This is equal to 3,520 feet per minute or $58\frac{2}{3}$ feet per second. According to the rule given in discussions on Mechanics, such a body would rise to a height of 53.5 feet. This is equivalent to 53.5 foot pounds of work for each pound of weight of the body. If now the pull of gravity were to be reduced to .112 of the weight, the body would rise to a height of

$$\frac{53.5}{.112} = 477.68 \text{ feet.}$$

This is exactly what takes place in the case of the application of the brakes to railway cars. Suppose a train to be moving at the rate of 40 miles per hour or 3,520 feet per minute, and the track on a slightly descending grade so that the propelling effect of the grade exactly equals the retarding effect due to journal friction and air resistance. If now, the brakes were applied so as to give a retarding effect of .112 of the weight, the train would be brought to a standstill in 477.68 feet. The kinetic energy of the body remains the same, and the direction of motion makes no difference, as long as the forces in operation remain unchanged.

Of course, such ideal conditions never occur. The grade varies, the brake shoe pressure changes, the coefficient of friction fluctuates, and the journal friction and air resistance are far from constant. As a result the distance covered before stopping is usually greatly in excess of the calculated. One of the chief reasons for this is the variation of the coefficient of friction. This varies between the same shoe and wheel on the same stop, with the speed of the train and the time during which the brakes have been applied. According to tests made in England by Capt. Galton the coefficient of friction between a cast iron shoe and a steel-tired wheel, varies from .058 at sixty miles an hour, to .34 at 5 miles per hour. Reverting to our previous calculation, for a car moving at 40 miles an hour, and assuming the smaller of these coefficients (.058), the car would have run 921.89 feet before stopping. With the greater coefficient the stop would have been made in 157.32 feet.

The time during which the shoes have been applied also causes the coefficient of friction to vary. At a speed of 27 miles per hour the coefficient of friction dropped from .171 at the commencement of the experiment to .072 at the end of 20 seconds.

Brake shoes are made of different materials. Soft cast iron is the standard. Other substances are used in order to secure greater durability and economy.

There are three methods of applying brakes to railroad cars: hand, vacuum and air power. In the first case the trainman turns a brake wheel attached to a shaft or spindle. A chain is wound on the spindle and, by a suitable arrangement of levers is made to apply the brakes. This arrangement will be described later.

The second means employed is the pressure of the atmosphere upon a diaphragm covering a vacuum. As the air is exhausted from the space beneath the diaphragm the latter is deflected and pulls upon a connection to the brake rigging, thus applying the brakes.

The third means is that of the expansive property of compressed air, and is the method employed in the air brake. The air is compressed by a suitable pump located upon the engine and is stored until needed for use. When it is necessary to apply the brake a portion of this stored air is allowed to pass into the *brake cylinder*. This cylinder is fitted with a piston which the escaping air moves outward. It is so connected with the brakes that its movement is communicated to the shoes and they are applied.

There are two types of air brakes that have been used in the United States: the *straight air* and the *automatic*. The straight air was first introduced and it involves the simpler mechanism. In the straight air brake the compressed air is stored in a large reservoir placed upon the engine. Under each car there is a brake cylinder with its connections to the brakes. Extending the entire length of the train there is a pipe with side openings leading to the several cylinders. The connections between the cars is made by a hose coupling. When the brakes are to be applied, the engineer admits air from the reservoir into the train-pipe. This air rushes into each cylinder and there applies the brakes on the car to which it is attached. When the brakes are to be released, the opening from the reservoir is closed, and the train-pipe opened to the atmosphere. The air in the pipe and cylinder thus escapes and springs force the shoes away from the wheels.

Straight air brakes are no longer used. They were a great improvement upon the old hand method of applying the brakes, but they were slow in application and release, and afforded no means of applying the brake from the train in case of accident.

The Automatic Brake has entirely superseded the straight-air brake, and the balance of this paper will be devoted to the former. The automatic brake, as its name implies, sets automatically in case of an accident. That is to say, if the train is broken, a hose or pipe bursts, or any part of the train-pipe is injured, the brakes will be automatically applied. It is also possible to apply the brakes to the whole train from any one car. In the straight-air design the brakes were applied by admitting air into the train-pipe. In the automatic type the brakes are applied by reducing the pressure of air in the train pipe. Hence, it will be seen, that, in any of the accidents enumerated above, the air will escape from the train-pipe, and the brake be applied. In order to make the application from any car, it is merely necessary to open communication to the atmosphere from the train pipe on that car.

The principle upon which the automatic air brake is operated is shown by the diagram Fig. 1. In this diagram A A represents the air pump which compresses the air and forces it into the main reservoir B. The valve C is the engineer's valve which is upon the engine. By means of this valve communication can be established between the reservoir B and the train-pipe D. Or, this communication may be broken and the air locked in these two receptacles. The opening from B may be closed and that from D into the atmosphere opened. E represents the triple valve through which the air passes to the auxiliary reservoir F, placed under each car. It also affords communication between the auxiliary reservoir F and the brake cylinder G when the brakes are to be applied.

An outline of the working of the mechanism is as follows: The pump A A is started and delivers the air under pressure to the main reservoir B. When the engine has been coupled to the train the engineer's valve C is opened and the air flows back through the train-pipe D to the triple valve E. Entering this valve it comes in contact with the piston *a* and pushes it to the extreme left of its stroke. When in this position, one side of the piston is spanned by a groove *b* in the casing, called the *leakage groove*. Air leaks through this groove into the space behind the piston and thence passes into the auxiliary reservoir F. When a sufficient quantity of air has passed this piston so that the pressure in F and the train-pipe D is the same, the car is said to be *charged*. It is now possible to apply the brakes. By turning the engineer's valve so that the flow from B is stopped and the air in D is allowed to escape into the atmosphere the work is accomplished. Lowering the pressure in D causes an excess to occur on the left hand side of the piston *a*. The air in the triple valve and auxiliary

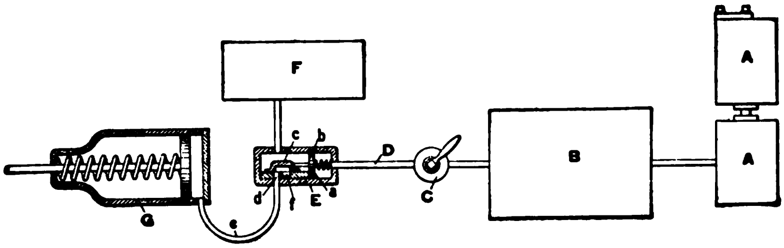


Fig. 1.

reservoir then starts to rush out through the leakage groove, but as it cannot escape rapidly enough to supply the loss in D, the piston *a* is moved to the right. Attached to the stem of the piston *a* is a small slide valve *c*. As the piston moves to the right this valve moves with it and so uncovers the port *d* leading to the pipe *e*. The line of communication is thus formed between the triple valve and the brake cylinder G. Hence, as soon as this port is uncovered the air from F flows directly into the brake cylinder and applies the brakes. Meanwhile, the piston *a* has traveled to the right, and beyond the end of the leakage groove *b*, stopping the flow of air from the auxilliary reservoir to the train-pipe. The brakes are now set and will remain in that position until released.

In order to release the brakes, the engineer re-establishes communication between the main reservoir B and the train-pipe D. Air again enters the triple valve. The piston *a* is pushed to the left. In this movement the slide valve *c* is shifted so that the flow of air from the auxilliary reservoir F into the brake cylinder G is stopped and communication opened between the brake cylinder and the atmosphere. This is accomplished by the passage way beneath the valve which establishes a communication between the port *d* and the exhaust port *f*; the latter being open to the atmosphere.

Such is the principle of operation of the air-brake as, at present, constructed. Great ingenuity has been displayed in the designing and construction of the details and each part will be taken up in its order and described.

At the present time there are two principal competitors, the Westinghouse Air Brake Co. and the New York Air Brake Co. Both brakes are operated on the same principle and they differ only in the mechanical construction of the parts.

The Pump. Fig. 2 illustrates in vertical section the eight-inch air pump as made by the Westinghouse Air Brake Co. The essential features are two tandem cylinders with their pistons mounted on a single rod and the valve mechanism in connection with each. The upper one is the steam and the lower the air cylinder. Referring to the engraving it will be seen that the valve is set vertically upon one side of the cylinder, that it is of the piston type and is fitted with an auxiliary operating piston at the upper end.

The main working pistons are fastened to the same piston rod. They are packed with the ordinary form of split packing rings sprung into grooves. The piston rod is hollow for a portion of its length. The air cylinder is fitted with two sets of ordinary check valves for admitting the air and allowing the same to escape after compression.

The lower head of the steam and the upper head of the air cylinders are cast in one piece with a convenient space between them for the insertion and manipulation of the stuffing boxes and glands about the piston rod.

The steam is admitted above and below the steam piston, as in the case of any steam engine, causing the piston to move up and down and operating the air piston beneath. The action is as follows: Steam is admitted from the boiler through the connection so marked into the steam chest (1). From here it has direct and constant access by the circular port (3), through a passage that is not shown in the engraving into the small steam-chest (4). In this steam-chest there is a small D valve (5). This valve is attached to the stem (6), which extends down into the main steam cylinder and into the hole in the piston rod. This valve rod terminates in a button at the lower end and has near its upper end, a shoulder. The intended use of the shoulder will be presently explained.

When the valve is in the position shown in the engraving, the steam passes from the steam chest (4), through the port and passage (7) into the upper end of the cylinder (8). Here it produces a downward pressure upon the reversing piston (9). In the construction of the piston valve of the pump, the reversing piston (9) and the upper piston (10) of the valve itself are of the same diameter. The lower piston (11) of the valve is of a smaller diameter. The result of this combination is that, when steam is admitted above the piston (9), the pressure there exerted balances the upward pressure beneath the piston (10). There is, then, an excess of downward pressure due to that exerted upon the piston (11) and the whole is pushed downward into the position shown in the engraving. When so set, steam passes from the steam-chest (1) through the small ports (12) into the port (13) and so into the lower portion of the steam cylinder. Here it forces the p
up. At the same time, the steam above the piston escapes t

the ports (14) into the passage (2), which runs in a belt around the cylinder and to the exhaust chamber (15). Thence it passes into the exhaust pipe and is led into the stack by a suitable pipe usually placed beneath the jacketing of the boiler.

As the main piston approaches the upper end of its stroke the reversing valve plate (16), which is bolted to the top of the piston, strikes the upper shoulder of the valve stem (6) already referred to. This movement pushes the valve (5) into its upper position. Here it covers the port (7) and the port (17) is placed in communication with the port (18) through the exhaust space in the valve (5). The port (18) leads by way of a small passage beneath the piston (9) into the exhaust passage (2). The steam in the cylinder (8), therefore, escapes through (17), (18) and (2) into the exhaust pipe. Under these circumstances the balance due to the equalization of the pressure above (9) and below (10) is destroyed. As the piston (10) is of larger diameter than (11). the excess of pressure upon the former tends to raise it and the whole moves into its upper position. In doing so the lower piston (11) uncovers the small port (19) and allows the steam beneath the main piston to escape into the passage (20) which corresponds to (2) at the top. It is thus led to the exhaust chamber (15) and the stack in the same manner as before. Meanwhile, the piston (10) rises so as to uncover the ports (21) and steam is admitted through them into the main cylinder above the piston, which is then driven down.

As the main piston approaches the end of its downward stroke the reversing valve plate (16) strikes the button at the lower end of the valve stem (6). The valve (5) is thus again carried down to the position shown in the engraving. Steam is admitted above the piston (9), the pistons of the valve are depressed and the steam again forces the main piston up.

The operations in the air cylinder are much more simple. The valve chamber on the right of the cylinder is fitted with four valves, (22), (23), (24) and (25). Of these (22) and (24) are the delivery and (23) and (25) the inlet valves. When the piston is rising, air is admitted through the small holes of the air inlet and, by raising the lower valve (25), flows into the cylinder. The compressed air produced by the upward motion of the piston passes out through the port, presses the valve (23) down against its seat and lifts the valve (22). Then it flows out through a passage not shown in the engraving, to the chamber (26), whence it is led to the main reservoir as indicated. During the downward stroke of the piston air is admitted through the upper inlet holes by lifting the valve (23). The air beneath the piston is, at the

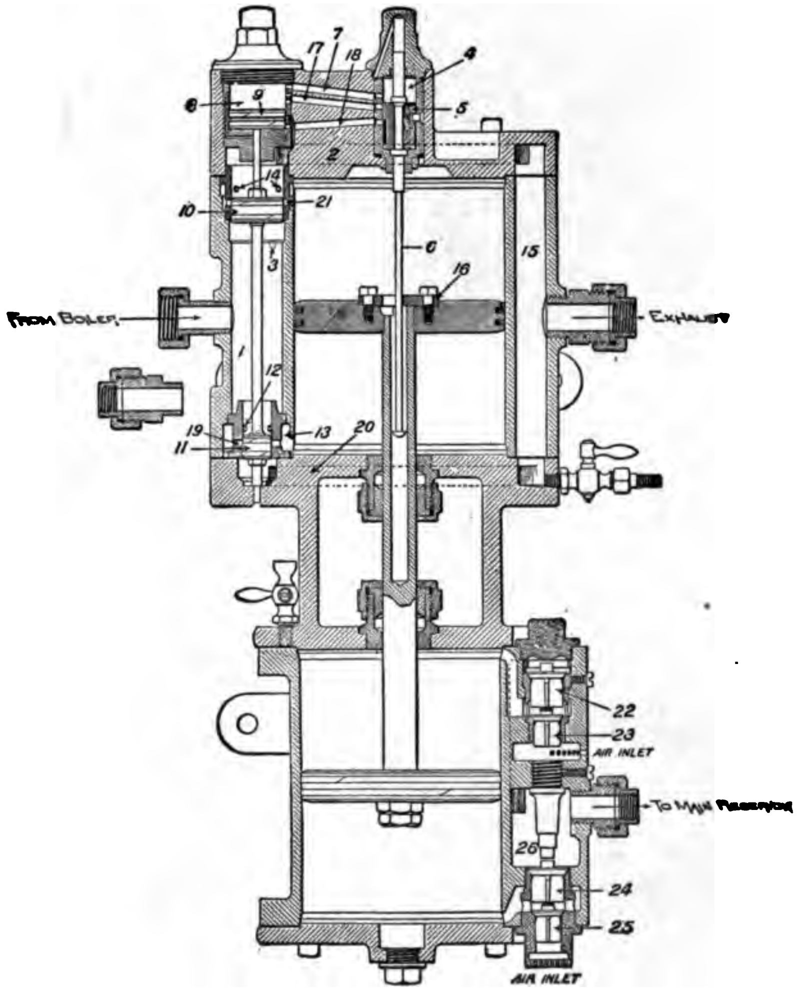


Fig. 2.

same time, forced out, into the chamber (26) and thence into the main reservoir by lifting the valve (24).

It will be noticed that a stop is screwed in above each of the delivery valves (22) and (24). This prevents an excessive lift and subsequent slamming of these valves. The lift of the inlet valves is also limited by the discharge valve above it. The motion of these valves is limited to $\frac{3}{32}$ inch.

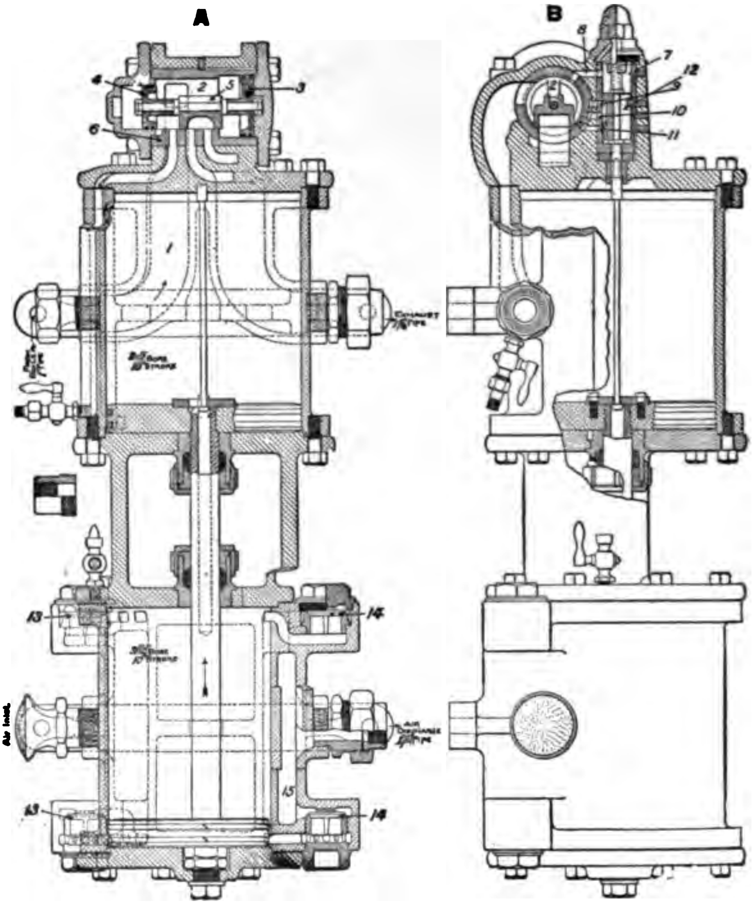


Fig. 8.

In the $9\frac{1}{2}$ inch Westinghouse pump shown in Fig. 3 there is a different arrangement of reversing valve mechanism. In this figure A and B represent two vertical sections at right angles to each other. The plane of A is parallel with the center line of the engine, and B with a line drawn transversely to the same The mechanism for the reversal of the pump acts upon the same principle as in the case of the 8-inch pump. The details of the construction are, however, quite different. The piston valve controlling the admission of steam into the cylinder is horizontal. Steam is admitted from the boiler at the point indicated. It flows through the passage (1), up and into the steam-chest (2), as indicated by the arrow. Here it is confined between the two pistons (3) and (4) of the main valve. Of these (3) is the larger in diameter. The stem connecting these two pistons passes through and is fastened to an ordinary D slide valve (5). Beneath this slide valve there are three ports, exactly like those of an ordinary steam engine. Of these the one at the left leads to the bottom of the steam cylinder; the one in the middle leads to the exhaust, and the one at the right leads to the top of the steam cylinder. In the position shown in the engraving (A) the valve is at the extreme right of its stroke and the port, leading to the bottom of the cylinder is open for the passage of steam.

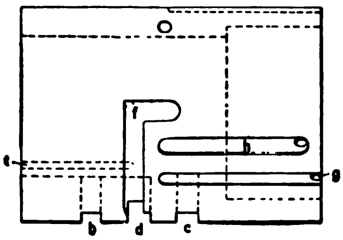


Fig. 4.

The bushing (6) beneath the valve is of a peculiar construction. It is shown in detail in Fig. 4. The main ports *b*, *d* and *c* are cut to correspond to the steam ports as already indicated. There is a small passage *t* through which any air or steam that may have found its way to the left of piston (4) can escape to the exhaust. The passage *t* maintains a constant communication between the chamber on the left of piston (4) and the exhaust or the atmosphere. There is, therefore, never any pressure exerted on the left hand side of the piston (4). As piston (3) is larger than piston (4) the greater pressure exerted upon the former by the steam in the chest (2) moves the whole reversing mechanism to the right until piston (3) strikes against the head of the cylinder. This opens the port at the left and allows steam to enter the bottom of the cylinder. The steam piston is fitted with a reversing valve plate exactly as in the case of the 8-inch pump. The piston-rod is also hollow and there is a reversing valve and rod of the same type. This valve is shown in section in B. The duty of this valve is to admit and exhaust the steam from the space between the piston (3) and head of the cylinder in which it moves.

Between the steam chests (2) and (7) there is a passage (8) maintaining a constant communication between the two. Hence boiler pressure always exists in steam-chest (7).

When the steam piston has reached the extreme lower end of its stroke the reversing valve plate has struck the button at the lower end of the valve rod and drawn the valve into its lower position as shown in B. In this position the ports (9) and (10) are connected by the cavity of the D valve. Of these ports (10) leads to the space in the cylinder between the piston (3) and the cylinder head; the port (9) leads to the exhaust pipe; and the port (11) leads to the passage *g* of Fig. 4, which runs out to the end of the cylinder between the piston (3) and the head.

As the steam piston approaches the upper extremity of its stroke, the reversing valve plate strikes the shoulder of the valve stem. The reversing valve (12) is thus raised so that the port (11) is opened to the steam in the chest (7). Pressure is, therefore, admitted through the port (11) of B and the passage *g* of Fig. 4 to the space between the piston (3) and its cylinder head. The piston (3) is now balanced by an equal pressure on each side of it. The result is that the pressure on the right hand side of piston (4) is the controlling one and this moves the valve to the extreme left of its throw. In this position the port openings are changed. The port on the right is opened to the steam in the steam chest (2), and the port on the left is connected with the exhaust through the cavity of the D valve (5). Steam is now admitted to the top of the main cylinder and exhausted from the bottom. This causes the piston to move down.

Approaching the lower end of its stroke, the reversing valve plate strikes the button on the end of the valve rod. This draws the valve (12) down into the position shown in the engraving; cutting off the supply of steam to the right of piston (3) and allowing that already there to escape through the port *h* of Fig. 4, thence through (9) of Fig. 3 to *f*, of Fig. 4 to *d* and finally out at the exhaust. This causes the pressures upon the two sides of piston

(3) to become unbalanced so that the pressure in the chest (2) again controls. The excess of pressure on piston (3) above that exerted on piston (4), causes the valve to be moved to the right again and take up the position shown in the engraving. This reverses the pump.

The construction of the air cylinder differs only in detail from the 8-inch pump as already described. There is a separate inlet and discharge valve for each end of the cylinder. The air inlet is protected by a wire gauze that causes the air to be divided into small particles on entering the cylinder. A passage cored in the cylinder leads from this inlet to a point beneath the inlet valves (13). The lift of these valves is limited to $\frac{3}{32}$ inch by a stop above them. Both valves are seated by gravity. These valves are indicated by dotted lines. The discharge valves (14) are of the same form. The space above them is connected by a cored passage, that is not shown, with the chamber (15) opening into the discharge pipe. The lift of these valves is also limited to $\frac{3}{32}$ inch by stops above them. In the case of the upper valves the stop is formed by the plug that is screwed in. The stops for the lower valves are a portion of the cylinder casting.

The duplex pumps made by the New York Air Brake Co., instead of having single steam and air cylinders, have two of each. Both steam cylinders are five inches in diameter. One air cylinder is five inches in diameter and the other is 7 inches. These dimensions refer to the No. 1 pump. In the No. 2 size, the steam cylinders are each 7 inches in diameter. The high pressure air cylinder is 7 inches in diameter and the low-pressure is 10 inches.

In the working of this pump, the steam cylinders act independently. The valve of one steam cylinder is operated by the piston movement of the other. Both air cylinders are filled with free air at every stroke. The first operation is to force the air from the largest air cylinder into the smaller one in addition to the free air already in the smaller cylinder. The smaller cylinder then contains three times its volume of free air compressed to a pressure of about 40 lbs. per square inch. The small or high-pressure piston then completes the compression and forces air into the reservoir. In this way the two 5-inch steam pistons are caused to drive the equivalent of three 5 inch air pistons by which a saving in steam is claimed.

The valve gear is very simple. For the steam cylinders it consists of two plain slide valves (5) and (6) that work in the steam chests (16) and (17). They are operated by the tappet rods (7) and (8) which extend into the hollow piston rods of the steam cylinders, in the same way as do the similar parts of the Westinghouse pumps. It will be seen from the engraving, Fig. 5, that the valve on one side controls the steam supply to the opposite cylinder.

In the position shown, the steam piston in cylinder (2) has completed its downward stroke. The reversing valve plate (20) has struck the shoulder of the tappet rod (8) and pushed the valve (6) into its lowest position. It will be seen that the port (23) leading to the top of cylinder (1) is now uncovered. Steam is, therefore, free to flow from the steam-chest (7) to the upper end of cylinder (1). At the same time the port (27) leading to the bottom of cylinder (1) is opened, through the exhaust cavity of the valve (6), to the exhaust port (19).

The piston (22) of cylinder (1) now moves downward under the influence of the steam admitted above it. Meanwhile the valve (5) controlling cylinder (2) and its piston (21) remains stationary, and steam continues to press that piston down against the bottom of the cylinder. As piston (22) approaches the bottom of its stroke, its reversing valve plate (20) strikes the shoulder on the tappet rod (7). This pushes the valve (5) down to its lowest position. Then the port (26) leading into the bottom of cylinder (2) is uncovered. Port (28) leading to the top of cylinder (2) is connected to the exhaust port. Steam, therefore, enters the bottom of cylinder (2) and is exhausted from the top. The piston (21) then rises. One piston is always at rest while the other is in motion.

The air valves are, like the corresponding valves of the Westinghouse pump, simple check valves. They seat by gravity while the piston is motionless.

The action of the air cylinders is as follows: With the pistons in the position shown, the cylinder (3) is filled with air under a pressure of about 40 pounds per square inch, and cylinder (4) is filled with free air. Piston (31) moves down and forces the air beneath it out through the valve (14) into the pipe lead-

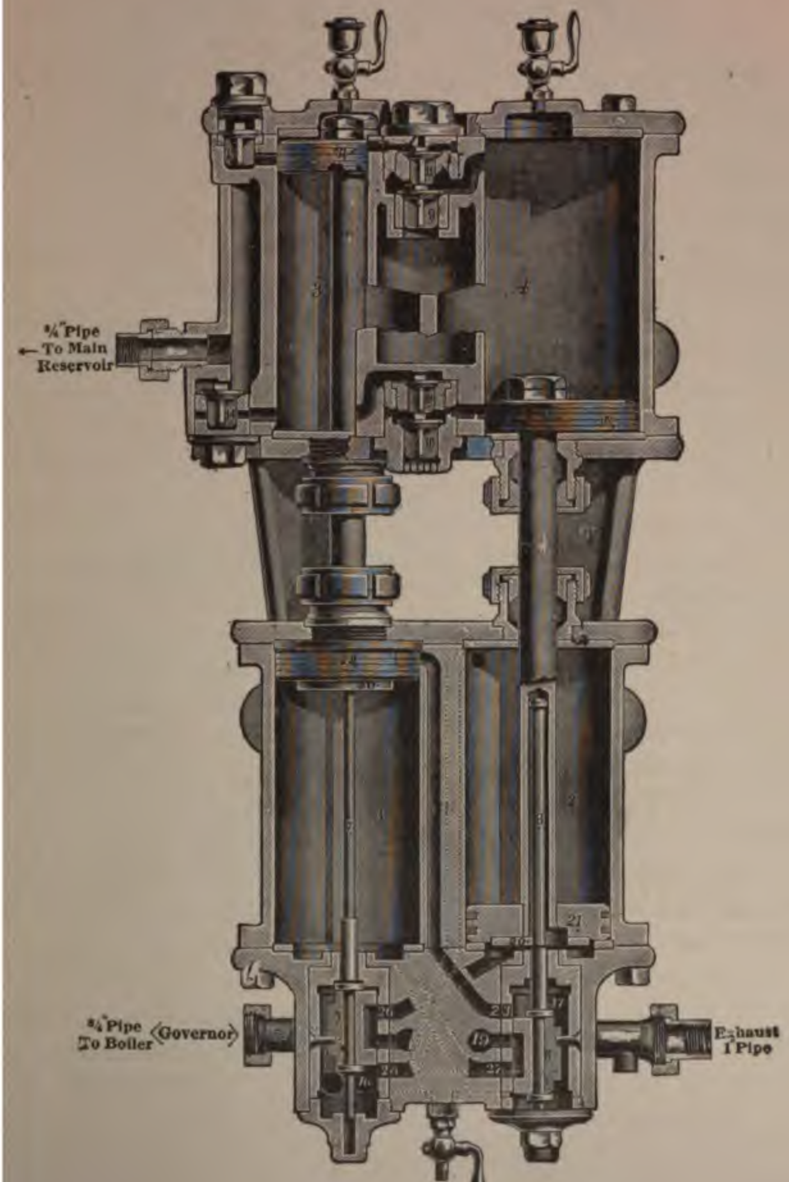

¾" Pipe
To Main
Reservoir
3
4
21
26
25
23
17
19
27
16
¾" Pipe
To Boiler
Governor
Exhaust
1 Pipe

Fig. 5.

ing to the main reservoir. At the same time it is drawing free air in through valves (9) and (11) to fill the space in the top of the cylinder. Hence, when it has reached the bottom of its stroke, both air cylinders are filled with free air. Piston (32) of the large cylinder now moves upward and forces the air above it out through valve (11) into the top of cylinder (3). At the same time it is drawing free air in through valve (10) to fill the space beneath it. Hence, when piston (32) has reached the upper limits of its stroke, the space beneath it is filled with free air ready for the return stroke, and the cylinder (3) is filled above its piston with air at a pressure of about 40 pounds per square inch.

On the upward stroke, the piston (31) of the small cylinder forces the air above it out through the valve (13) whence it flows by a cored passage, that is not shown, into the discharge pipe to the main reservoir. At the same time it draws air into the bottom of the cylinder through the valves (10) and (12).

The details of the piston packing and air valves are similar to those in use on the Westinghouse pumps.

The Main Reservoir. By referring to the plate at the end of this paper it will be seen that the pump delivers its air directly into the main reservoir. This is made of boiler plate and is substantially riveted together. The size varies from a capacity of about 11,200 cubic inches to 20,000 cubic inches, dependent upon the service for which the engine is intended. It is recommended that, for passenger engines, the capacity should not be less than 26,000 and for freight engines, not less than 20,000 cubic inches. These reservoirs serve as a storage place for the air supply. This supply is drawn upon to release the brakes, after they have been applied, and to charge the auxiliary reservoirs under the individual cars. The air in the main reservoir is not drawn upon in applying the brakes.

The main reservoir is located at any convenient point on the locomotive. It may be anywhere between the pilot and the back bumper on the tender.

The Pump Governor. It is evident that unless some means of controlling it is provided, the pump will continue in operation until it is stalled by the accumulated pressure in the main reservoir. This would result in a varying pressure in the latter dependent upon the steam pressure in the boiler. In order that the engineer may have complete control of the brakes of a train, it is necessary that the pressure in the main reservoir should be nearly constant. For this purpose the pump governor is used.

This device is so designed that the admission of steam to the pump is controlled by the air pressure in the main reservoir. As will be seen by reference to the plate, a pipe is led from the main reservoir to a pressure gauge by way of the engineer's valve, and hence on to the pump governor. This governor is also set in the steam pipe between the boiler and the pump. It is shown in vertical section in Fig. 6. The connections to the boiler and the pump are shown at the bottom of the engraving. When the pump is working, steam enters at the connection at the left, passes through beneath the valve (1) and thence on to the pump. As

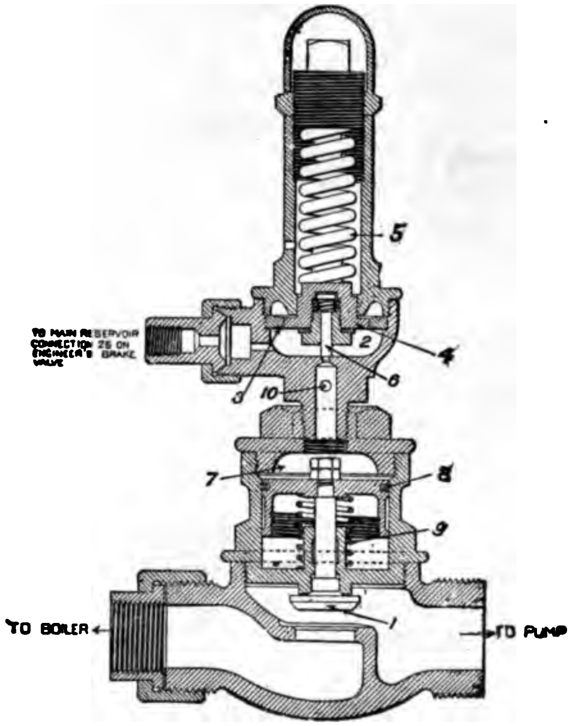


Fig. 6.

the pressure in the main reservoir rises, air flows from it into the space (2). This space is closed at the top by a sheet metal diaphragm (3) which is fastened to a piston (4). This piston and diaphragm are held down by the spring (5) set above it in an enclosing case. The tension of the spring is regulated by a nut in the casing above it. The tension is adjusted so that the diaphragm will yield and with it the piston when any predetermined pressure has been reached in the main reservoir. Attached to the piston there is a small pin valve (6). Under normal conditions the spring (5) forces the piston (4) down and the pin valve is held against its seat. When the pressure in the main reservoir has risen to the point where it raises the diaphragm by compressing the spring (5) the pin valve (6) is lifted from its seat. This permits air to flow past and down into the chamber (7). This chamber is above the piston (8). Piston (8) is fastened to the stem of the steam valve (1). When the pump is working, the valve is held open by the spring (9). As the air from the main reservoir flows into the chamber (7) the piston (8) is forced down until the valve (1) is closed. This cuts off the steam supply from the pump and the latter stops.

When the releasing or recharging of the brakes or any other cause has lowered the pressure in the main reservoir the spring (5) again closes the pin valve (6). The air that is then confined below it and above the piston (8), leaks out into the atmosphere through the hole (10). Such a leakage destroys the pressure on the piston (8) and it is raised by the combination of the steam pressure beneath the valve (1) and the spring (9). As it rises the valve (1) is opened and the pump is again started.

Since the diaphragm (3) is securely clamped between the diaphragm ring above it and the casing below, there is little likelihood of any leakage of air blowing around it. Should, however, any such leakage occur, it can escape into the atmosphere through the hole shown in the side of the casing. Thus any accumulation of pressure above the diaphragm is prevented.

When the pin valve (6) is opened and there is a pressure upon the piston (8), there is a constant leakage of air into the atmosphere through the leakage hole (10). This escape of air will lower the pressure in the main reservoir just rapidly enough to make the pump work very slowly. Such action keeps the parts hot and prevents a condensation with a consequent accumulation of water in the steam cylinders.

The pump governor supplied by the New York Air Brake Co., acts in the same manner with but insignificant variations in the details of construction.

Engineer's Valve. This portion of the air brake apparatus is usually called the engineer's valve. The full technical name is the *Engineer's brake and equalizing discharge valve with feed valve attachment.* The function of the engineer's valve is to give the engineer a complete control of the flow of air and with it of the brakes upon the train. There are five positions of the handle of this valve, namely: the full release, running, lap, service application and emergency application. The full release position is used when the brakes are to be released. The running position is the one in which the handle is set when running upon the road. When so set there is a sufficient flow of air from the main reservoir to the train-pipe to compensate for any leakage that may exist and to keep the auxiliary reservoirs fully charged. In the lap position all of the ports of the engineer's valve are blanked so that there is no passage of air from one point to another. In the service position the flow of air from the main reservoir into the train-pipe is cut off, and there is a slow discharge of air from the train-pipe into the atmosphere. This causes the brakes to apply gradually and moderately. In the position of emergency application the flow of air from the main reservoir into the train-pipe is also cut off and there is a sudden and rapid discharge of air from the train-pipe. This causes the brakes to apply rapidly and with full force.

The mechanism of the engineer's valve is somewhat complicated and will require careful study to master it.

The first form of engineer's valve used was practically nothing more than a three-way cock. With it, it was almost impossible to secure the proper reduction of train-pipe pressure. There was also great danger of making an emergency application when a service one was required.

The latest form of Westinghouse engineer's valve, known as the F 6 valve, is shown in vertical section in Fig. 7. It will be seen that there are four pipes leading into this valve. They run to the main reservoir, the train-pipe, the black hand of the pressure gauge and to the equalizing reservoir.

The valve is manipulated by the handle (1) which is fastened to the rotary valve (2.) This valve is so arranged that the passages within it combined with the ports beneath enable the engineer to execute any desired manipulation of the brakes. The flow of air in the five positions of the engineer's valve is as follows:

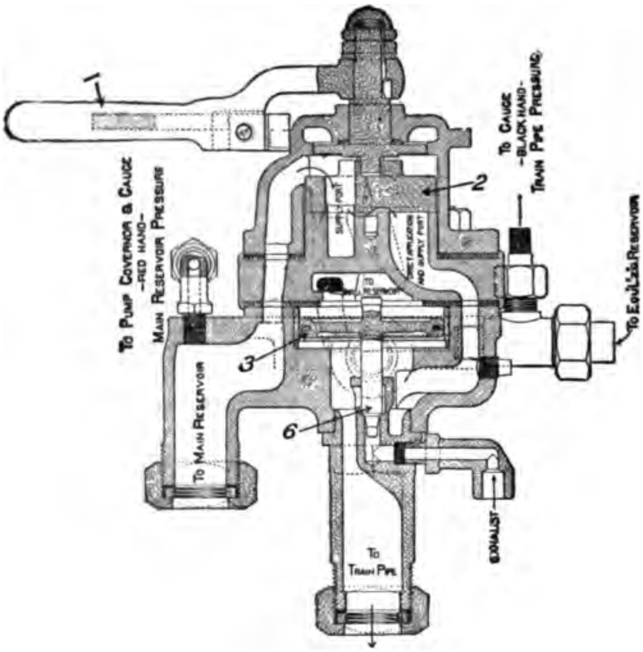


Fig. 7.

First. The full release position. The handle is shown in this position in Fig. 7. When so set there is a direct connection between the main reservoir and the train line through a large port and between the main reservoir and the small brake valve reservoir through two small ports. The air flows from the main reservoir up to the engineer's valve, which it enters at the main reservoir connection as indicated. It enters the rotary valve from the top through the supply port, and passes directly down to the port in the seat beneath as shown in Fig. 7. In this port it passes around the stem and bearing of the rotary valve, as indicated by the arrow, and into the direct application and supply port. The engraving shows that this port runs down and connects directly with the train-pipe. As the air passes through the cavity on the lower side of the rotary valve (2), to the direct application and supply port, it is free to pass through the equalizing port (Fig. 9) into the cavity marked "to small reservoir." When in this position another small port in the rotary is over the preliminary exhaust port in the seat, which also has a connection leading to the small reservoir.

It will thus be seen that the main reservoir pressure has access, at all times, to the top of the rotary valve. Hence, when in the release position, the air flows directly into the train-pipe and the brake valve reservoir. This flow continues until the pressure in these two places is equal to that of the main reservoir. This standard pressure is 90 pounds per square inch.

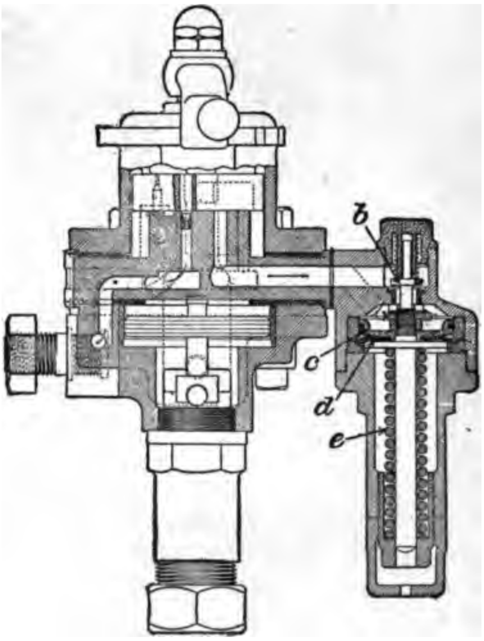


Fig. 8.

As the standard pressure for the train-pipe is but 70 pounds, a small hole, of about the diameter of a pin, allows the main reservoir pressure to blow out, thus warning the engineer that he will obtain full main reservoir pressure in the train-pipe, if he allows the valve to remain in the full release position for too long a time. This accumulation of train-pipe pressure is obviated by moving the valve into the

Second or Running Position. In this position all of passing to the train-pipe must flow through the feed valve or train-pipe governor which is shown at the right of Fig. 8. When in this position, the air flows from the main reservoir down through the rotary valve, into the feed port and out through the horizontal passage to the top of the train-line governor.

The Train Line Governor is a reducing valve set to cut off the flow of air when the pressure in the train-pipe has reached a pressure of 70 pounds. The construction of the governor is very simple. There is a stiff spring *e* held in a case at the bottom which presses up against a disc and diaphragm *d* above which there is a piston *c*. The stem of the controlling valve *b* is pressed down against the top of the piston by a light spring at the top. Air enters at the top and flows down beneath the valve *b* and into the cavity above the piston *c*. It then turns and flows out to the

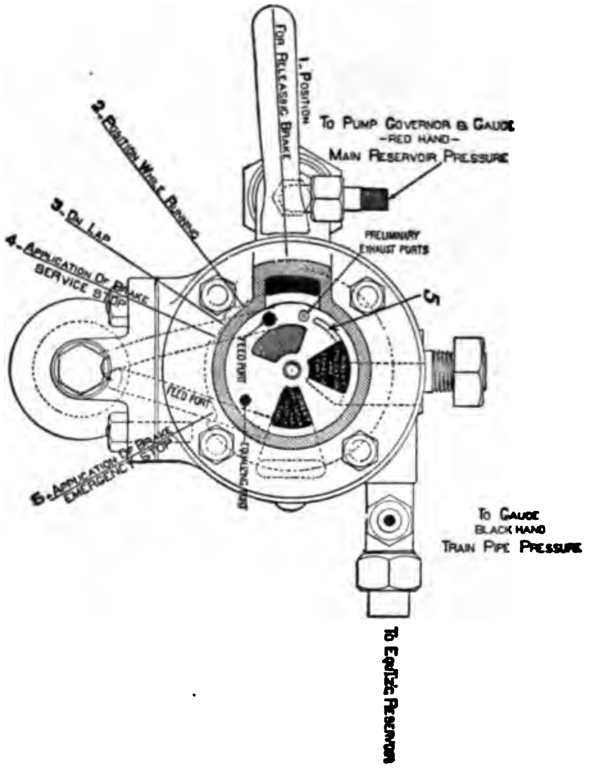


Fig. 9.

train-pipe through the port shown by dotted lines leading up to the left. As the pressure rises above the piston *c*, the latter is forced down compressing the spring *e* until, when a pressure of 70 pounds has been reached, the spring is compressed to such an extent that the valve *b* is permitted to close and thus cut off a further supply of air.

Third. The Lap Position. In this position there is no flow of air whatever through the engineer's valve. All of the ports are covered and a lug on the inside of the rim of the rotary valve also covers the equalizing port, so that there is no connection between the brake valve reservoir and the train-pipe. In this position the main reservoir, the train pipe and the brake valve reservoir are cut off from one another and are by themselves.

The point of separation between the train-pipe and the brake valve reservoir, at this time, is the small piston (3) of Fig. 7. If the packing in the piston were to be perfectly tight it would be possible for all of the train-pipe pressure to leak away without lowering that in the brake valve reservoir. As a matter of fact, however, this packing is seldom, if ever, perfectly tight so that a leak in the train pipe causes a leak from the brake valve reservoir to occur past the piston (3). This reduces the pressure in the reservoir, which is indicated by the pointer on the pressure gauge.

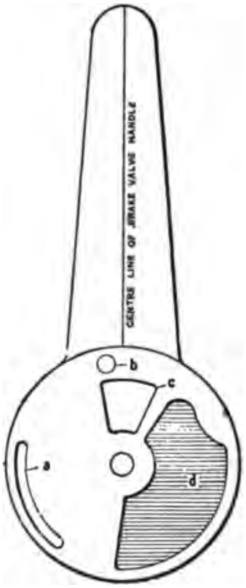


Fig. 10.

Fourth. Service Position. This position is used in order to make a gradual application of the brakes. Here a groove *a* in the rotary valve face Fig. 10, connects the preliminary exhaust port shown in Fig. 9, with the groove (5) in the seat. The preliminary exhaust port connects with the small drum and the groove (5) runs to the direct application and exhaust port, which, in turn, leads out to the atmosphere. This makes a direct connection from the small brake valve reservoir to the atmosphere and lowers the pressure above the piston (3). Previous to the placing of the engineer's valve in the service position the pressure above and below the piston (3) was the same, and it was down against its seat. The reduction of the pressure above allows the train pipe pressure to lift it. The stem (6) of the piston (3) terminates in a valve which closes the opening to the exhaust. When the piston rises this valve opens and the air from the train-pipe is free to flow out through the exhaust into the atmosphere. This outflow of air will continue as long as the train-pipe pressure is greater than that of the small drum or brake valve reservoir. As soon as the latter is in excess, the piston (3) is again forced down and the valve on the stem (6) is seated. It will be seen that, for a gradual application of the brakes the engineer takes air from the small drum and not from the train-pipe.

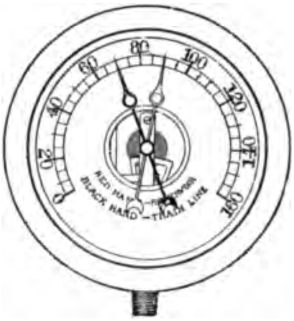
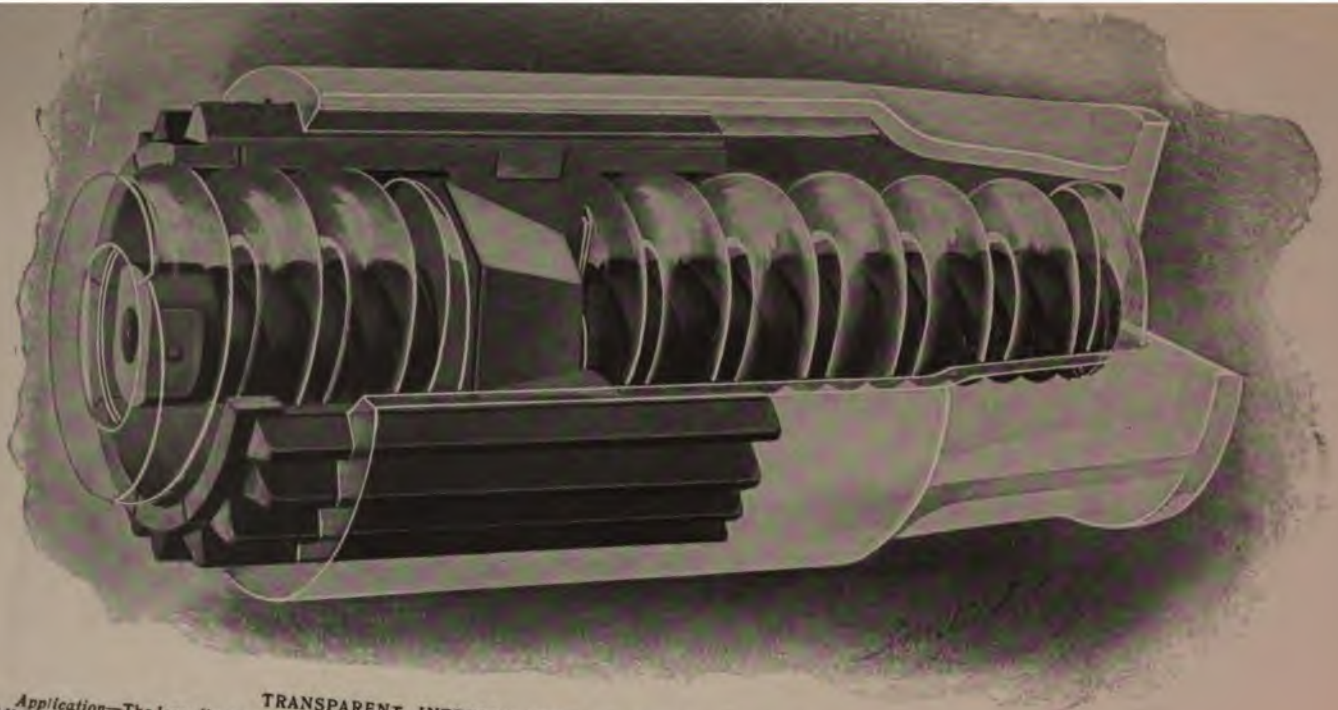


Fig. 11.

Fifth. The Emergency Position. The object of the emergency position is to give a very free flow of the train-pipe air into the atmosphere and thus get a sudden reduction of pressure in the same. To do this the valve handle is moved around so that the large cavity *d* Fig. 10, of the rotary valve is directly over the large ports in the seat (Fig. 9) that are marked "direct application and exhaust port" and "direct application and supply port." Air then passes direct from the train pipe up through the supply port, traverses the cavity *d* (Fig. 10) of the rotary valve and escapes out at the exhaust port into the atmosphere. In this application the reduction of pressure in the small reservoir plays no part whatever. To make an emergency application of the brakes, it is not necessary that there should be a heavy reduction of train-pipe pressure. It must, however, be sudden. The reason for this will be fully explained in the description of the action of the triple valve.

In order to manipulate the brakes properly the engineer's valve must be turned as follows:

It must be held in the full release position for only sufficient time to release the brakes and not to allow main reservoir pressure to accumulate in the train-pipe.



TRANSPARENT INTERIOR VIEW OF WESTINGHOUSE FRICTION DRAFT GEAR.

Application—The large "preliminary spring" at the left absorbs ordinary stresses and forces the friction strips against the friction cylinder. The small spring gives additional pressure on the wedge. When both springs become compressed, the friction strips are moved with increasing resistance, absorbing a pressure of over 150,000 lbs. before completion of stroke.

Release—The small spring at the left releases the wedge and the large spring returns friction strips to normal position, practically without recoil.

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For charging the auxiliary reservoirs and maintaining the proper pressure in the train-pipe the engineer's valve should be in the running position.

After a service application of the brakes, the placing of the valve on lap will retain the brakes so set. With the valve on lap and the train-pipe empty, ninety pounds pressure will accumulate in the main reservoir and nothing in the train-pipe.

A continued application of the valve in the service position will cause a full-powered application of the brakes.

The opening of the emergency ports, causes a sudden and full-powered application of the brakes.

The Brake Valve Reservoir is made in a manner similar to that of the main reservoir except that it is smaller. It is 10 inches in diameter and 12 inches long. It, therefore, contains about 840 cubic inches of air. The connection between it and the engineer's valve is made as short as possible.

The Pressure Gage. Referring to the folded plate at the end of this paper, it will be seen that the pressure gauge is connected both to the main reservoir and the small brake valve reservoir. This gauge (Fig. 11) is made especially for this purpose and carries two hands mounted on concentric pivots. One hand is red and serves to indicate the pressure existing in the main reservoir. The other hand is black and indicates the pressure in the train-pipe. The object of using the two colors is to avoid confusion and to enable the engineer to ascertain the pressures that he is carrying at a glance. While the black hand is used to indicate the train-pipe it will be remembered that it is really connected with the small brake valve reservoir, whose pressure is the same as that of the train-pipe.

In following the train-pipe back from the engineer's valve, we first come to a stop cock by which the passage may be closed. This is an ordinary plug valve. Beyond this are the hose and hose couplings, which serve to make the connections between the engine and the cars of the train. At each end of each car there is a plug cock, known as an angle cock by which the train-pipe may be closed. The construction and uses of these parts will be taken up later.

The Triple Valve. On each car the train-pipe is connected by a short branch pipe to the triple valve. This valve is called a triple valve because it has three things to do: charge the auxiliary reservoir, apply the brakes and release the same. This valve is made in several different forms which will be taken up in succession.

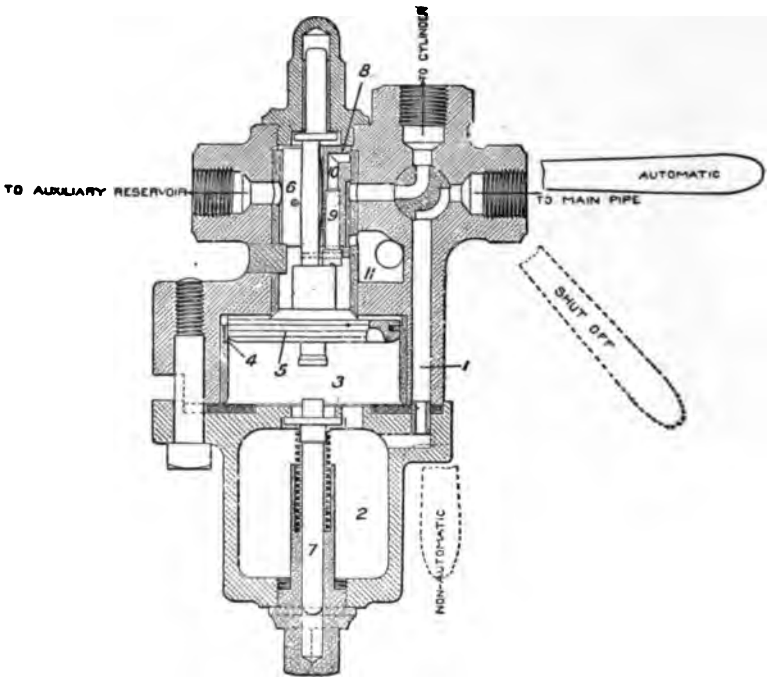

Fig. 12.

The Plain Triple is illustrated in vertical section in Fig. 12. There are three pipe connections: one each to the auxiliary reservoir, the brake cylinder and the train-pipe. One one side there is a four-way cock whose handle may be set in any one of three positions. When placed as shown in the engraving the brake is automatic. Giving it one-eighth of a turn down into the shut-off position will cover all three passages into the cock. This places the brake out of service. If the handle is given a quarter turn, it will be seen that the passage now connecting the brake cylinder and the auxiliary reservoir, will connect the brake cylinder to the train-pipe. In this position the brake is non-automatic and is operated by straight air. That is to say, the method of operation is to admit air into the train-pipe and allow it to pass direct into the brake cylinder.

The valve was used in this way during the transition period when the automatic brake was being introduced.

When set for automatic action the air enters from the train-pipe and passes down through the passage into the lower chamber (2). Thence, it flows into the cylinder (3) beneath the piston (5) and forces the latter into its upper position as shown. On one side of the cylinder there is a small leakage groove (4) through which the air escapes past the piston and into the valve case (6) above. From this point it enters the auxiliary reservoir.

In applying the brakes the engineer makes a reduction in the train-pipe pressure. This lowers the pressure in the cylinder (3) beneath the piston (5). The air in the auxiliary reservoir then forces the piston down until it strikes against the stem (7) situated beneath it. As the piston moves it carries the slide valve (8) with it. In this slide valve there is a side passage shown by the dotted circle, which is opened and closed by the graduating valve (9). This graduating valve is attached to the stem of the piston (5) by a small pin as shown by the dotted lines. The valve (8) has some play on the stem of the piston. Hence, when the piston starts downward, it moves a short distance and carries the graduating valve away from its seat before moving the slide valve (8). When the piston is down against the stem (7) the slide valve is moved so that the port (10) in the valve (8) is opposite the port leading to the brake cylinder. Air then enters the side opening of the valve (8) from the auxiliary reservoir, flows beneath the regulating valve (9) and into the brake cylinder. As soon as the pressure in the auxiliary reservoir has fallen so that it is equal to the train-pipe pressure, the piston (5) rises slightly and closes the regulating valve (9). The brakes are then applied with a moderate pressure.

To release the brakes the engineer admits air from the main reservoir into the train pipe. This raises the pressure in the cylinder (3) and forces the piston (5) to the upper limits of its stroke. In this movement the slide valve is carried to the position shown in the engraving, in which the port to the brake cylinder is connected with the passages to the atmosphere (11) through the cavity shown beneath the slide valve (8). Air thus escapes from the brake cylinder. At the same time the recharging of the auxiliary reservoir takes place through the leakage groove (4) past the piston (5).

When an emergency application of the brakes is to be made, there must be a sudden reduction of train-pipe pressure. This causes the piston (5) to be forced down so rapidly and violently as to strike a sharp blow on the stem (7). Such a blow compresses the spring by which the stem is held in its normal position and thus permits of a greater travel of the piston. This greater travel is shared by the slide valve (8), which is moved down past the opening to the brake cylinder. The air then has a large and unrestricted opening from the auxiliary reservoir directly into the brake cylinder. As a consequence the flow of air is very rapid and a full-powered application of the brakes takes place at once.

This valve is efficient and serviceable upon short trains. Upon long trains, however, it was found to be too slow in its operation. The reason is that all of the reduction of train-pipe pressure must take place through the engineer's valve. As a consequence there is so great a lapse of time between the reduction causing application on the front and rear cars of a long train, that the latter are subjected to exceedingly violent shocks. In the tests made at Burlington in 1886, with this valve on a train of fifty cars the time elapsing between the application on the engine and the last car was from 9 to 22 seconds. This was accompanied by "a fearful shock at the rear end," due to the last cars running with an unchecked velocity into those in front. The experience there obtained led to the invention of the *Quick Action Triple*. This valve is shown in the running position and in vertical section in Fig. 13. There are three connections to the auxiliary reservoir, the train pipe and the brake cylinder respectively as in the plain triple. The action and general construction of the piston and slide valve are the same as in the valve just described. There is, however, some variation in minor details. The object of the quick action valve is to hasten the reduction of the train pipe pressure and thus shorten the interval between the application of the brakes on the first and last cars of the train.

In ordinary service applications there is no difference in the action of the plain and the quick-action triples. The two valves will work together perfectly in the same train. It is only in cases of an emergency application that the quick-action feature comes into play. The parts that have been added to the plain triple in forming the one under consideration are: the strainer (1) at the train-pipe connection, an additional port (2) in the slide valve (3), the removal of a corner of the slide valve as shown in Fig. 15, the emergency piston (4), the rubber-seated valve (5) and the train-pipe check (6).

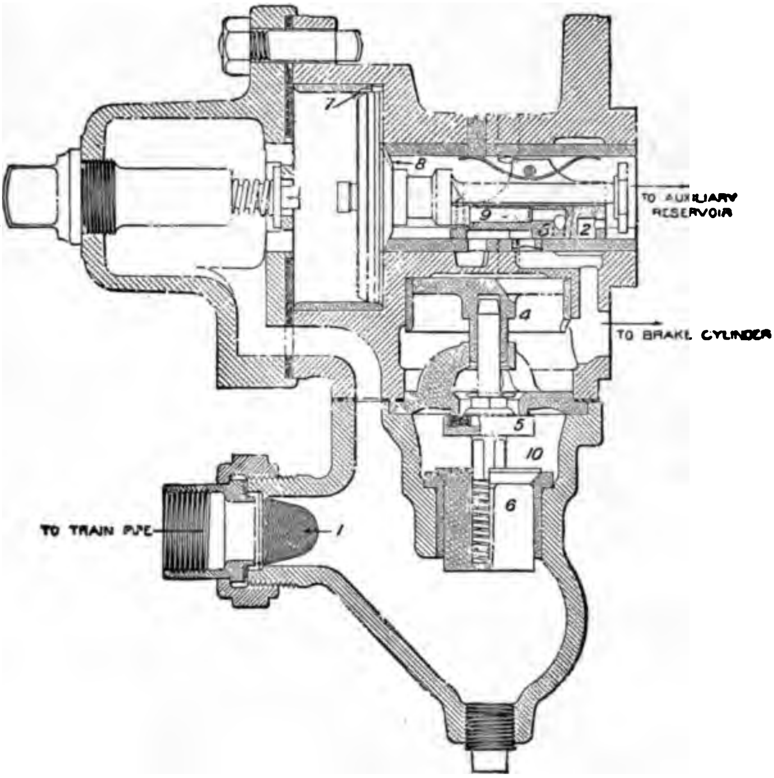

Fig. 13.

The strainer serves to keep particles of dust from entering the triple valve from the train pipe. Dirt in the triple is apt to settle in the small leakage grooves (7) and (8) and thus check the flow of air to the auxiliary reservoir. The action of the valve in an emergency application of the brakes is as follows:

It will be noticed that there is a hole (indicated by dotted lines) rising from the space above the emergency piston (4) up through the valve seat. When the valve is in the running position as in Fig. 13, this hole opens in the valve seat beneath the cavity of the slide valve (3). But, when the piston and slide valve have been thrown violently to the left by a sudden reduction of train-pipe pressure, the port leading from the regulating valve (9) opens into this hole as shown in Fig. 14. Air can thus pass from the auxiliary reservoir through the regulating valve to the top of the emergency piston (4). This air then forces the piston (4) down and opens the rubber seated valve (5). The air that had previously been confined in the chamber (10) then

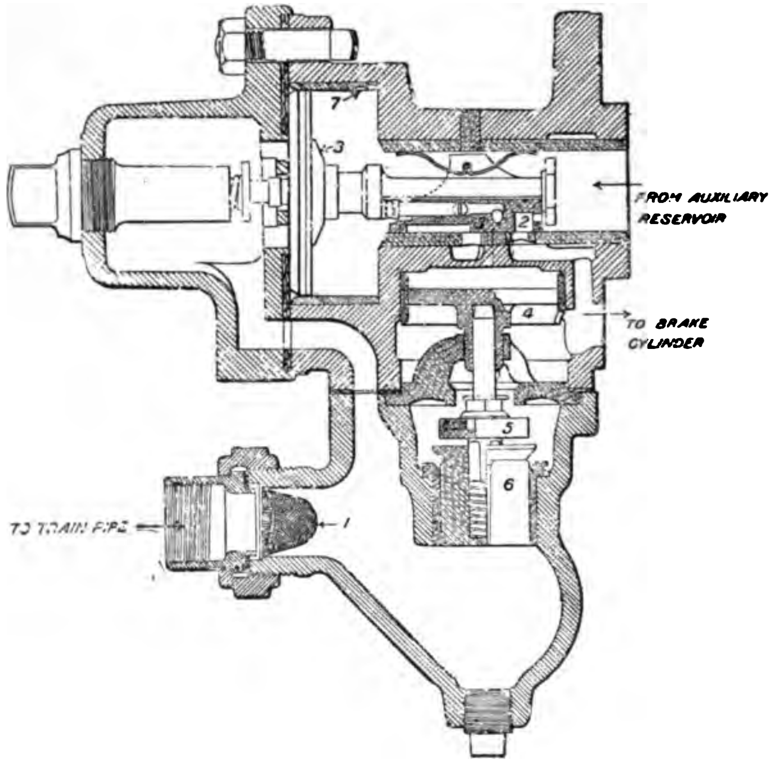

Fig. 14.

escapes into the brake cylinder. This relieves the pressure on top of the valve (6) which is opened upward by the train-pipe pressure beneath it. The opening of the valve, with the rubber-seated valve down, allows the air in the train-pipe to escape directly into the brake cylinder, thus increasing the pressure in the latter, while that in the former is suddenly reduced. The triple valve is then in the emergency position as shown in Fig. 14. It will be seen from this that each triple valve serves to make a sudden reduction of pressure on its own car. This reduction is thus passed along from car to car with the result that the interval between the application of the brakes on the first and last cars of a fifty-car train has been cut down to 2½ seconds. There is also a saving of air effected by allowing the train-pipe to exhaust into the brake cylinder instead of into the atmosphere through the engineer's valve.

The Driver Brake Triple is a modified form of the plain triple. The difference lies in the fact that there is no four-way cock by which it can be converted to a straight air brake and in the proportioning of some of the parts. In operation and in all essential particulars the two valves are identical.

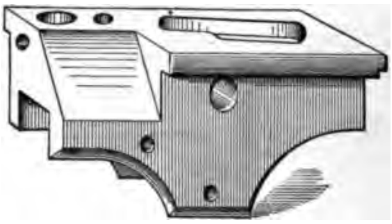

Fig. 15.

The Brake Cylinder. All of the mechanisms heretofore described are for the purpose of producing and releasing the pressure in the brake cylinder. This cylinder is shown in section in Fig. 16, with the triple valve attached. The cylinder is made of cast-iron with heads bolted to each end. In it there is a piston into which the piston rod (2), or as it is commonly called, the *push rod* is fastened. To the outer end of this push rod a casting is fastened. The jaw in this casting serves as a point of attachment for the levers of the brake rigging which will be described later. The piston is of cast iron and is packed by a leather cup packing (3) which is held out against the wall of the cylinder by the packing expander (4). The latter is merely a split ring of circular section that is sprung into position beneath the leather.

The leather is held in position by a follower-plate (5) which is bolted to the piston by tap bolts.

When the brakes are to be applied air flows from the triple valve into the back end of the cylinder and forces the piston to the right, compressing the spring (1). When the air pressure is released, the spring forces the piston back to the left and draws the brake levers with it.

In Fig. 16, the brake cylinder used in passenger service is illustrated. Here the auxiliary reservoir is made of steel plates riveted in a cylindrical form as in the case of the main reservoir. A variation is made in the construction of the apparatus used in freight service. Fig. 17 illustrates the freight car equipment.

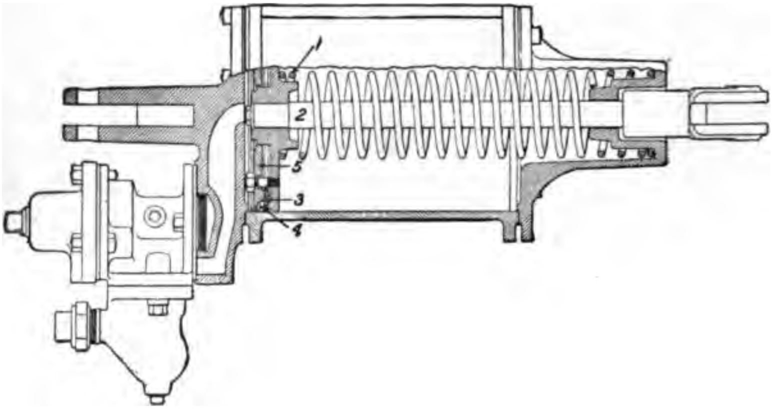

Fig. 16.

In this the auxiliary reservoir is made of cast iron. The triple valve, the auxiliary reservoir and the brake cylinder are all bolted together. Instead of bolting the triple valve to the brake cylinder it is bolted to the auxiliary reservoir. The connection between the triple valve and the brake cylinder is made by means of a pipe (1) running through the auxiliary reservoir. There is no connection between the brake cylinder and the reservoir except through the triple valve as already explained. The piston of the freight brake cylinder is the same as that of the passenger cylinder. There is, however, a difference in the push rods. In the freight cylinder this is a piece of pipe into which a rod connected to the levers projects. This rod has a bearing at the inner end of the pipe, directly against the piston. The triple valves are essentially the same. The freight equipment is the more compact of the two.

Attachments. There are a number of parts connected with the air brake apparatus that need attention. These are the angle cocks, hose, hose couplings, dummy couplings, drip cups and conductor's valve.

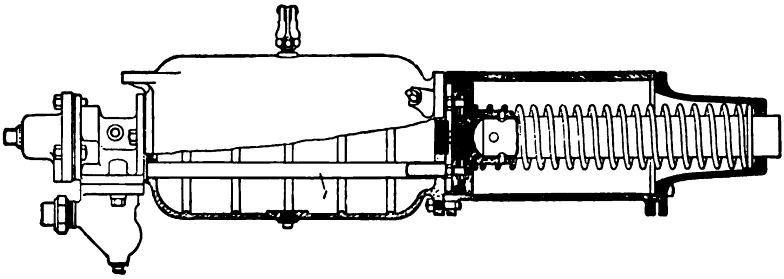

Fig. 17.

Angle Cocks are merely plug cocks such as shown in Fig. 18 with one connection turned down for the attachment of the hose. The horizontal connection leads to the train-pipe. One angle cock is placed at each end of each car. When the train is connected all of the angle cocks are opened with the exception of the rear cock on the last car. This is kept closed in order to close the train-pipe and prevent the air from blowing away.

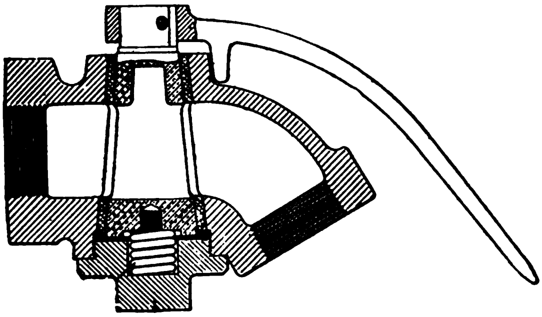

Fig. 18.

Brake Hose is made of layers of strong duck and rubber. The standard used has an inside diameter of $1\frac{1}{4}$ inches and is 22 inches long. Such a length of hose is shown in Fig. 19, with its nipple and coupler attached. The nipple Fig. 20 is threaded at one end to screw into the angle cock. The other end is forced into the hose and then held in position by clamping the hose band Fig. 21 over it.

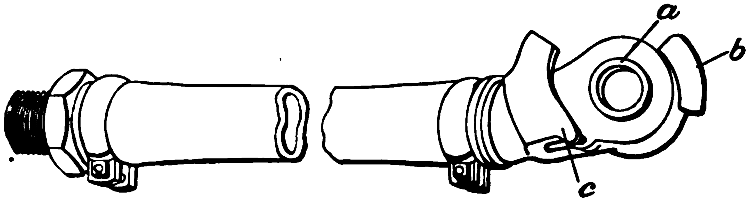

Fig. 19.

The Hose Coupling is shown connected to the hose in Fig. 19. It is a malleable iron connection that is pressed into the hose and held in the same manner as the nipple already described. The connection between two pieces of hose is made by laying the two faces *a* of the couplings together and then turning them so that the lug *b* of each slips beneath the lip *c* of the other.

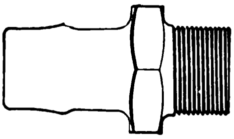

Fig. 20.

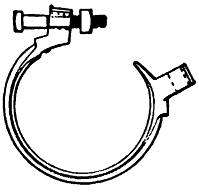

Fig. 21.

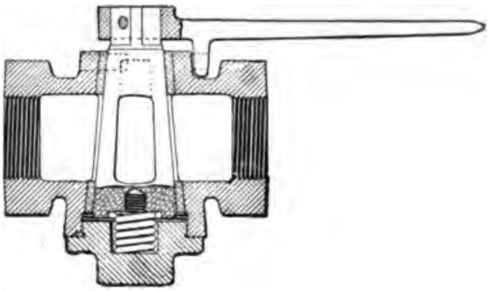

Fig. 22.

The Cut-Out Cock, (Fig. 22) like the angle cock is an ordinary plug valve. It is placed in the branch pipe that leads off from the train-pipe to the triple valve on each car. Its object is to render inoperative the brakes on the car to which it is attached. This is sometimes necessary on account of a defective triple valve or other cause. It thus becomes possible to cut out the car containing the defective parts while the train-pipe still remains open to carry the air back for operating the cars behind it.

Car Drain Cup is shown in section in Fig. 23. It is placed in the train-pipe and presents an unobstructed flow to the air. The cylindrical mesh extending through it serves to catch any dust or dirt that may have found its way into the train-pipe. The triple valve is thus protected.

The Dummy Coupling (Fig. 24) is a blank coupling attached to the end of the car body. It is used to hold the disengaged end of a hose at the rear of a train.

The Conductor's Valve is a simple plug valve connected with the train-pipe. In ordinary conditions it is closed. It is only opened in cases of emergency when it becomes necessary to apply the brake from some car on the train. By opening it the air is allowed to escape from the train-pipe and an emergency application of the brakes is made.

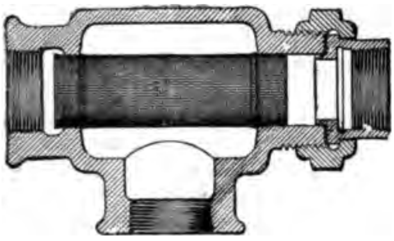

Fig. 23.

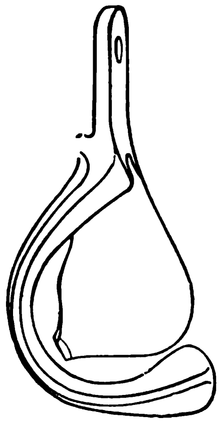

Fig. 24.

The Pressure Retaining Valve (Fig. 25) is an important attachment and is very extensively used upon freight cars and upon passenger equipment of mountain roads. Its duty is to retain a pressure of fifteen pounds in the brake cylinder after the brakes have been applied. It consists of a plug cock of which the plug forms a three-way cock. It is connected by means of a $\frac{3}{8}$-inch pipe with the exhaust part of the triple valve. When it is not in use the air can escape from the triple and pass out through the side opening shown by a dotted circle back of the plug. When in use this hole is closed and the escaping air must pass beneath the weighted valve (1). The weight (2) is of such a size that it requires a pressure of more than fifteen pounds per square inch to lift it. Hence, after the brakes have once been applied, the engineer cannot release them entirely. When he puts the handle of the engineer's valve into the release position, the air lifts the valve and escapes until its pressure has been reduced to 15 pounds. The valve then closes and the shoes are applied with that pressure. It is then possible for the auxiliary reservoirs to be recharged while the brakes are applied with this moderate pressure. The pressure-retaining valve is usually placed near the brake standard on freight cars or under the bonnet on passenger cars. The place chosen is usually inaccessible so that trainmen or others may be prevented from tampering with it when it is in use. It serves to hold trains on down grades and allow the engineer to replenish his reservoirs while still retaining control of the train.

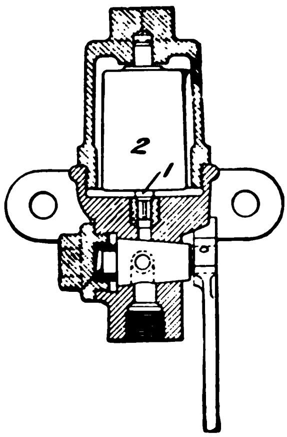

Fig. 25.

Defective Mechanism. Like other pieces of machinery, each part of the air-brake mechanism requires care and attention, in order that it may be kept in good working order. Defects in the mechanism are usually the result of neglect or carelessness.

Operating the Pump. When starting the pump, it must be done slowly. If a full head of steam is turned on at once, the pump will race and slam. This is because there is no back pressure of air upon which the steam pressure can be cushioned. The pump should be run slowly until a pressure of from thirty to forty-five pounds has been accumulated in the main reservoir. Care must also be taken that the water of condensation is entirely drained out of the steam cylinder before starting at full speed.

The pump does not need a great amount of lubrication. Some pumps have been run without any for a number of years, and, at the same time, been kept in good condition. As clean machinery works more successfully than dirty, it is necessary to keep the pumps clean. This work may be done by working a hot solution of lye and water through the air cylinders, having first disconnected the delivery pipe, so that it will not pass into the main reservoir.

The oil suited for use on an air pump is West Virginia oil, or one that will not dry and form gum.

If the valves stick and do not open easily, they can frequently be started by tapping the cases with a hammer. If the air valves do not open promptly at the beginning, and then remain open until the end of the stroke, it is a sign that the piston packing is leaking. Leaky packing may, therefore, be detected by listening at the suction inlet. If the suction draws throughout the whole stroke, the packing is all right, otherwise it will be found in a leaky condition.

If the pump pounds, it may be due to any one of a variety of causes. Anything that will allow the piston to strike the pump head will cause pounding. A common cause is the upsetting of the reversing valve stem or plate, by the incessant striking to which it is subjected. Tight valves that move with difficulty will, by springing the rod, cause pounding. It may also be due to an excessive lift of the air valves. Frequently, it is easily accounted for by some obvious defect. At other times, it is only revealed by a careful inspection.

Heating is a source of trouble with air pumps. In stationary compressors, the air cylinders are surrounded by a jacket of cold water. This keeps the cylinder cool. No such arrangement is possible on an air-brake pump. Hence, when a pump is run continuously for a long time, it is certain to become heated by the heat generated in the compression of the air. When a pump has become hot, it should be stopped and allowed to cool. This cooling may be hastened by pouring cold water over it. Never pour water over a pump that is in motion. The variation in the contraction will be sure to bind the piston and cause it to stick or cut.

If a pump does not run for its full stroke, the trouble will usually be found to lie in the reversing valve or stem.

As the pump is the life of the air-brake system, it is usually located on the right-hand side of the engine, directly in front of the engineer, so that any trouble will be quickly noticed. Sometimes the necessities of the case require that it shall be located elsewhere.

The pump governor is designed to limit the pressure in the main reservoir to ninety pounds per square inch. One of the chief sources of trouble with the governor is the accumulation of dirt about the diaphragm valve (6 of Fig. 6). This may produce either one of two opposite effects. If the dirt accumulates so that there is a constant leak beneath the valve, the pressure in the piston cavity (7) will stop the pump too soon. If the dirt accumulates so that the diaphragm is slightly raised without a leakage occurring past the valve, the pump will run too long and

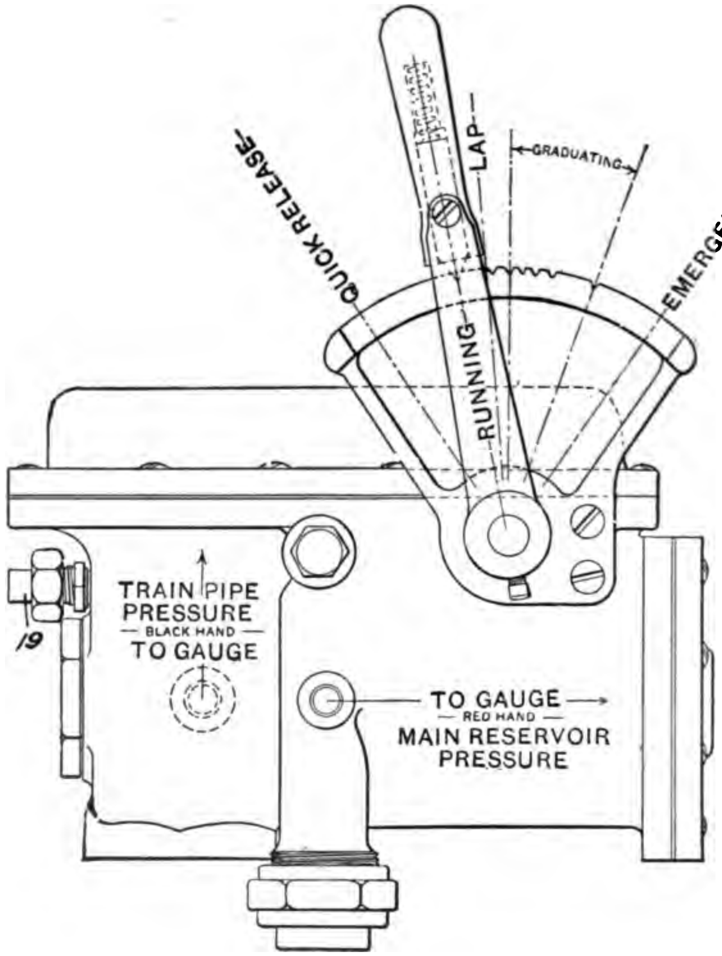

Fig. 16.

thus raise the pressure in the main reservoir above what it ought to be.

Leakages are the source of more trouble with the air brake than any other one cause. There are innumerable points at which this may occur. It occurs most frequently in the train-pipe. A leakage at some point in the train-pipe is readily detected by the falling of the black pointer of the gauge. If the leak is a large one, it may be difficult or impossible to maintain a pressure in the train-pipe sufficient to operate the brakes. A slight leak may have the same result as the making of a slight service application of the brakes. To locate a leak, it will be necessary to commence at one end of the train and inspect all of the parts until the leak has been found. Leaks most frequently occur in the hose and its connections. When the leak is in the coupling, it can sometimes be checked or stopped by driving a wedge back of the lug *b*, Fig. 19. This forces the faces *a* together with a heavier pressure which may stop the leak.

A leak is very apt to occur in the brake cylinder. It is usually due to dry or badly-worn packing. The danger of such a leak is that it causes the brakes to come off after having been applied.

As the triple valve is the automatic feature of the brake, it is sensitive to defects in all parts of the apparatus. Therefore, it is no sign that, because it fails to act properly, it is, in any way, defective. The triple valve will not work as it should if there is a deficiency of pressure in the auxiliary reservoir; if strainers are too dirty to allow the air to escape from the train-pipe side with sufficient rapidity to cause the brakes to set; if there is so much moisture in the air as to cause the escaping air to freeze the exhaust shut.

Trouble, belonging to the triple itself, is almost always due to the accumulation of dirt. A blow from the train-pipe is usually due to the imperfect seating of the emergency valve. The failure of this valve to seat is ordinarily caused by an accumulation of dirt.

Sometimes an emergency application will take place when it is not wanted. This may be caused by the graduating valve failing to seat properly; by a weak graduating spring; by a broken graduating valve pin, or by gum and dirt about the valve preventing it from moving freely, and by the main piston sticking so that a considerable reduction of pressure is required to move it. The peculiar feature of the last source of trouble is that, with a light reduction of pressure, the sticking piston will be the last to move. When it does move, it starts violently and produces an emergency application on the car to which it is attached. This produces an emergency application on all the other cars of the train.

An accidental application of the brakes, while running. is usually due to a leak in some part of the train-pipe. The same cause may produce a dragging of the brakes which cannot be called an actual application.

It may be set down as an axiom that, if the parts are well cared for, the air brake will always work as it should.

In the location of troubles with the air brake, it will be well for the inspector to notice whether or not the apparatus has been properly erected. The piping should be free from pockets where moisture can accumulate. Those charged with the maintenance of the apparatus should see to it that all parts are regularly drained. Especial care should be taken to keep the main reservoir free from water. An accumulation of water at this point will be sure to be a source of trouble with the triples at the front end of the train. This holds good with especial force in cold weather.

New York Engineer's Valve. The New York Air Brake Company uses an engineer's valve that is radically different from the Westinghouse, which has already been described. The peculiar feature of this valve is that it has an automatic regulation of the train-pipe reduction of pressure in service applications. The valve is shown in side elevation in Fig. 26. From the lettering on this engraving, it will be seen that the positions of the handle correspond to those of the Westinghouse valve. That is, there are the release, running, lap, service (here called graduating) and emergency positions. It will be noticed that there are several notches in the graduating portion of the quadrant. The handle may be placed in any one of these notches, and the escape of air from the train-pipe will be cut off when the corresponding reduction of pressure has taken place.

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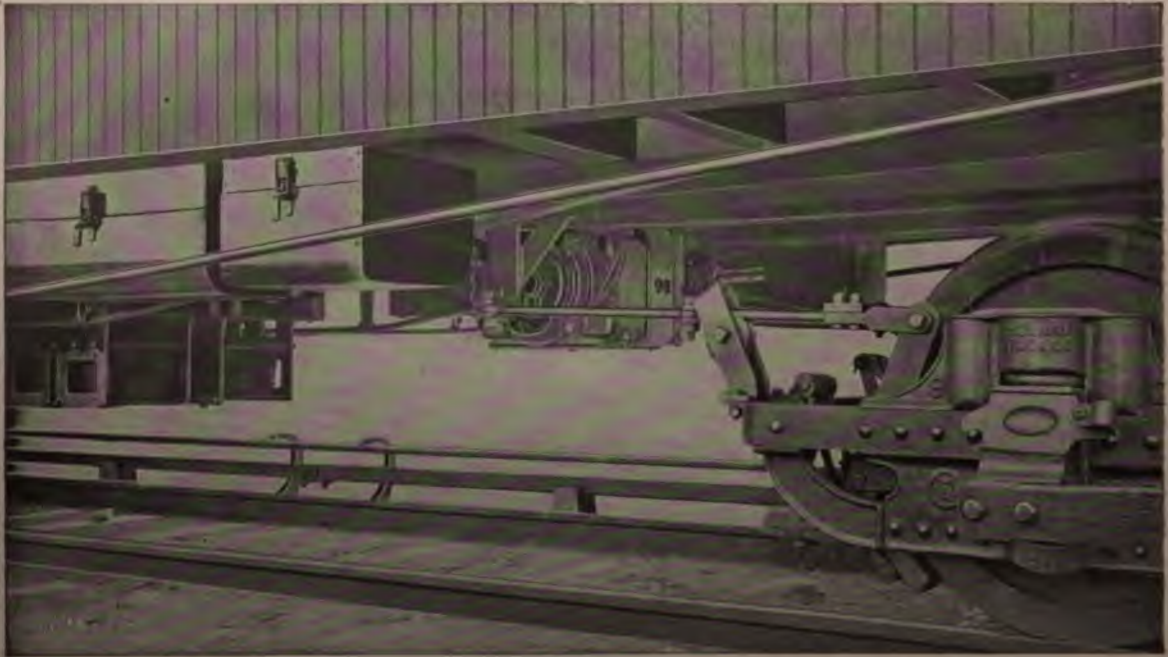

Under Section of Electric Car Showing Air Compressor, made by General Electric Co.

The operation of the valve will be understood from a study f the sections, Figs. 27, 28 and 29. Air is admitted from the main reservoir directly into the valve case (1). The main slide alve (2) is moved to and fro by the bell crank (3) and the conection (4). The former being keyed to the shaft carrying the andle. The chamber (5) is connected with the train-pipe. When the valve is in the running position, as shown in Fig. 27, ir passes from the valve case (1) through the side passage, shown y dotted lines in Fig. 29, to the space beneath the feed valve (6).

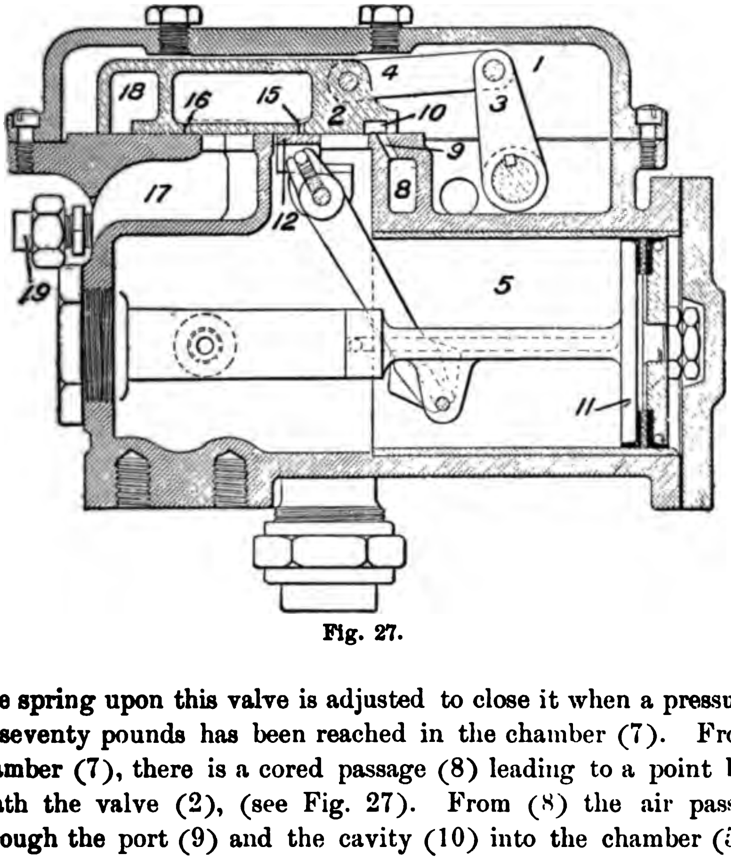

Fig. 27.

The spring upon this valve is adjusted to close it when a pressure f seventy pounds has been reached in the chamber (7). From hamber (7), there is a cored passage (8) leading to a point beneath the valve (2), (see Fig. 27). From (8) the air passes hrough the port (9) and the cavity (10) into the chamber (5), nd thence into the train-pipe. The chamber (5) is of circular ection, and in it there is a piston (11). The stem of this piston s made to operate a small slide valve (12). The valve is moved o the right as the piston moves to the left. The space between the piston (11) and the cylinder head is connected to a small engineer's valve reservoir, which may be located at any convenient point. This reservoir is subjected to train-pipe pressure. It is filled by air from the train-pipe, passing through a cavity (13) in the valve to the hole (14). One end of (14) leads into the space between the piston (11) and the cylinder head, and the other to the small reservoir connection (19).

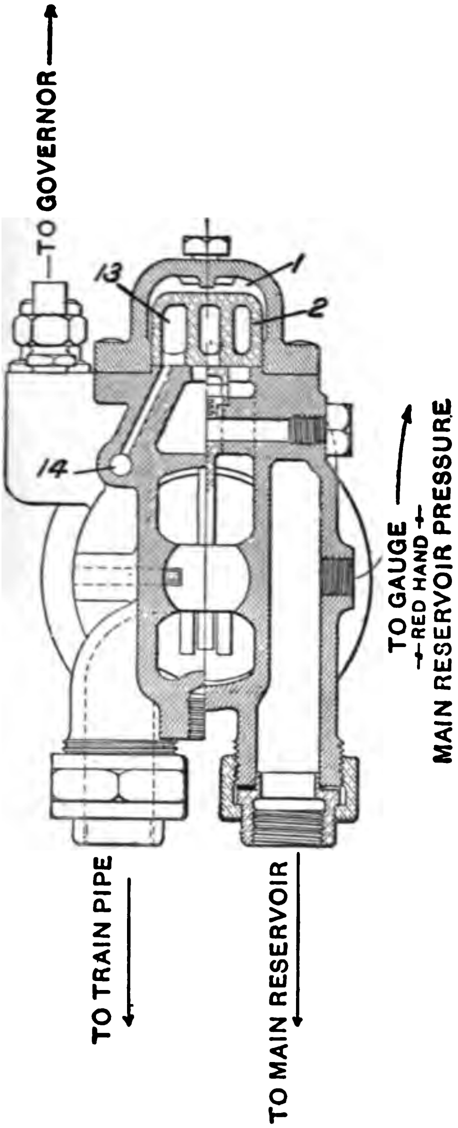

Fig. 28.

To make a service application, the handle (Fig. 26) is moved to the right and set in one of the graduating notches. This moves the valve (2) to the right until the ports (15) and (16) are opened, respectively, into the chambers (5) and (17). Chamber (17) opens directly into the atmosphere. Air thus escapes from the train-pipe and its pressure is reduced. As soon as this occurs, the air in the small reservoir expands and pushes the piston (11) to the left. This action carries the valve (12) to the right until it has covered the port (15) of the main valve. As soon as this port is covered, there can be no further reduction of train-pipe pressure until the operating handle is set in another graduating notch to the right. When this is done, the air in the small reservoir expands until the port (15) is again closed by the valve (12). When the handle is on lap, all ports are closed and there is no feed into the small reservoir.

To make an emergency application, the valve (2) is moved to the extreme right of its throw. When in this position, air escapes from the chamber (5) through the ports (13) (Fig. 30), and the side passages of the valve (2), out through the port (18) and into the exhaust (17). When in this position the movement of the piston (11) has no effect in stopping the escape of air. The valve (12) is between the ports (13), and does not cover them in its movement to the right.

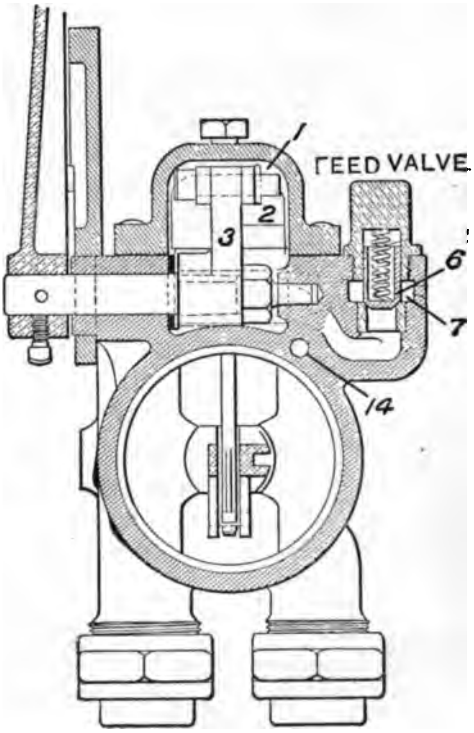

Fig. 29.

The advantage accruing from the use of this valve is that the engineer is not obliged to watch the pressure gauge to determine the train-pipe reduction, the train-pipe reduction is definitely fixed for each position of the handle.

The Brake Rigging. Up to this point attention has been confined to the construction and operation of that portion of the brake apparatus upon which the air works direct. It is now necessary to take up the system of rods and levers by which the power is carried from the brake cylinder to the shoes that press against the wheels. In order to make this portion of the mechanism as uniform as possible, the Master Car Builders' Association has adopted standard methods of doing the work. A diagramatic sketch of these standards is shown in Fig. 32. Four methods are required. Referring to diagram A, it will be seen that the first application of the power comes from the cylinder *a*, wherein the air pushes out the push rod *b*. The outer end of this push rod is attached to a floating lever *c*, known as the cylinder lever. There are three other connections to this lever. At one end there is a connection *d*, leading to the hand-brake staff. Between the push-rod *b* and the other end of the lever there is a connection *e*, called a ***floating connecting rod***. The outer end of the cylinder lever is fastened to a brake connection *f*, which leads to the top of the live lever *g* of the truck.

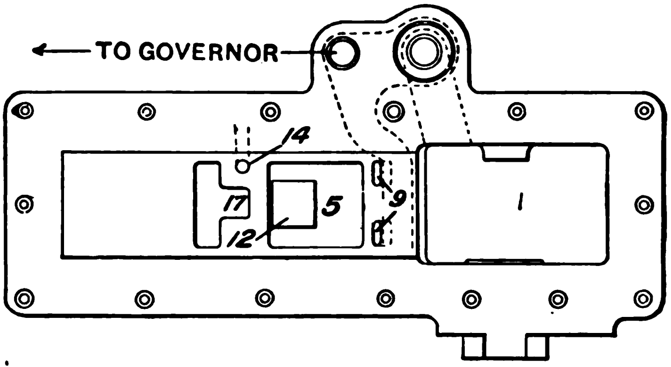

Fig. 31.

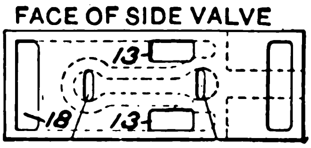

Fig. 30.

Going in the other direction, the floating connection rod takes hold of the floating lever *k* which is fastened at one end at *l*, and, at the other end, takes hold of the brake connection *f'*. Beyond this point, the connections are the same at each end of the car. The connections at the truck are shown on a larger scale in Figs. 33 and 34. Fig. 33 represents the arrangement for trucks with ***inside-hung*** brakes and Fig. 34 for ***outside-hung***. The signification of these terms are that in inside-*hung* brakes the shoes are between the wheels of the truck. On outside-hung, they are outside the wheels. On freight cars, present practice puts a great majority of the shoes between the wheels. On passenger cars, the shoes are usually outside the wheels.

Referring to Fig. 32, the arrow-head on the lines of the diagram show the direction in which the power is applied. Thus the air forces the push-rod *b* out in the direction of its arrow-head against the cylinder lever *c*. This motion moves *d* in the direction of its arrow-head, and slakens the chain leading to the brake staff. The effect is to leave that end of the cylinder lever free as though nothing were fastened to it. As the lever *c* moves out, it comes to a bearing on the rod *e*, and moves the latter in the direction indicated by its arrow-head. As the parts to which *e* is attached come to a bearing, the lever *c* turns and pulls upon *f* in the direction indicated by its arrow-head. The connection *f* then pulls upon the upper end of the live lever *g* of the truck.

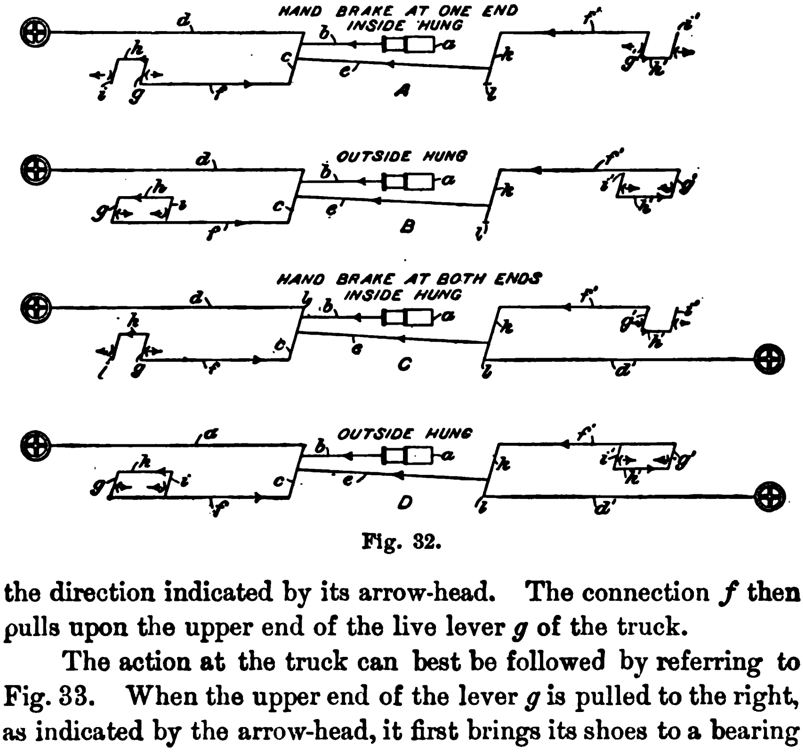

Fig. 32.

The action at the truck can best be followed by referring to Fig. 33. When the upper end of the lever *g* is pulled to the right, as indicated by the arrow-head, it first brings its shoes to a bearing against the wheels, and then, turning about the shoe or brake-beam connection, puts a compression stress on the rod *h*, moving it in the direction of its arrow-head. This motion of *h* turns the ***dead lever*** *i* about its upper pivotal point and pushes the corresponding shoe against its wheel. The upper end of the dead lever *i* is pivoted to a fixed point.

The pull on the connection *e* (Fig. 32) turns the floating lever *k* about the fixed pivot *l*, drawing the brake connection *f'* in the direction of its arrow-head. The connection at the trucks is the same as that already described in the reference to Fig. 33.

If the brakes are to be applied by hand, the chain attached to the rod *d* is wound about the brake-staff. This turns the cylinder lever *c* as before, and applies the brakes in the same way. In order to avoid moving the brake cylinder piston, when applying the brakes by hand, the push-rod is not fastened to it. The push-rod extends to the bottom of the pipe, shown attached to the piston in Fig. 16. When the brakes are applied by hand, the push-rod moves away from its contact with the piston.

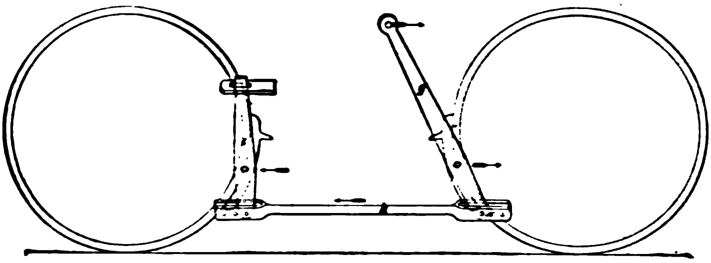

Fig. 33.

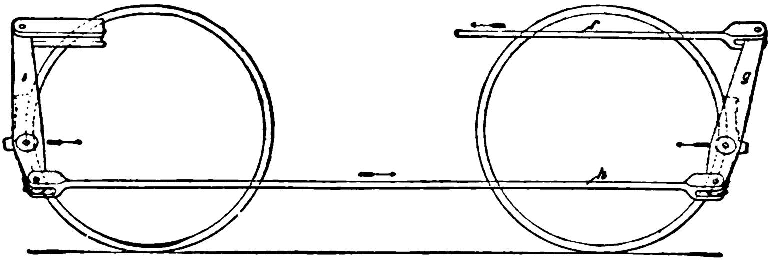

Fig. 34.

In C of Fig. 32 the mechanism is the same as at A in every respect except that the end of the lever *k* has a bearing against a stop at *l* which prevents that end from being moved in towards the center of the car. This stop serves to protect the connection *d* from being subjected to any stress, except such as may be directly applied to it by its own brake staff. When such a pull is applied the end is moved away from the stop and the brake applied as already described. When the brakes are hung outside the wheels the only difference is that of the truck connections. This can be most easily understood by referring to Fig. 34. The pull is carried by the rod *f* past the centre of the truck to the live lever *g*. With inside-hung brakes the live lever is between the truck center and the center of the car. With outside-hung brakes the live lever *g* is between the truck centre and the end of the car. When the pull of *f* is communicated to the upper end of the lever *g* the latter presses its shoes against the wheels and pulls, with its lower end upon the tie-rod *h*, as indicated by the arrow. The pull of *h* is transmitted to the dead lever *i*. The lever turns about a fixed pivot at the upper end and forces its shoes against the wheels. Similar parts of A, B, C and D are referred to by similar letters. The reader can, therefore, easily follow the lines of pull and use the description applying to A for assistance.

The arrangement of levers described is the standard adopted by the Master Car Builders' Association. A plan of the arrangement is shown in Fig. 35. Attention is called to the arrangement of the stop for the floating lever *k*.

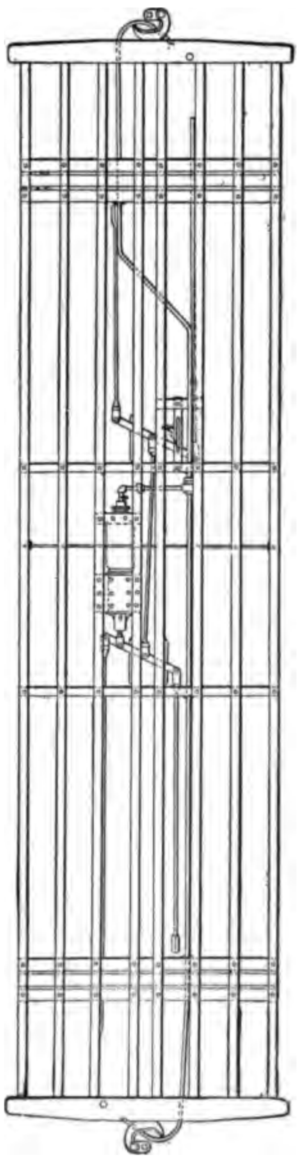

Fig. 35.

While this system of levers is the standard it is not always used. There are some variations. One of these for inside-hung brakes is shown in Fig. 36. The connection *f* extends beyond the center of the truck as in outside-hung brakes. It takes hold of the upper end of the live lever *g* as in the standard. The thrust rod extending between the live and dead levers is above instead of below the shoes or beams. When the pull of *f* is transmitted to *g* the latter turns on the end of *h* and applies its shoe. The thrust bar *h* is then pushed against the dead lever *i*. The upper end of *i* is attached to a fixed pivot as before. As the thrust of *h* is communicated to *i* it turns about the fixed point and applies the brakes as indicated.

It will be noticed that in all of the arrangements the shoes are interfulcrumed. That is to say, each shoe serves as a fulcrum for all of the rest. The result is that no shoe exerts any real braking force upon the wheel until all of the others have come to a bearing.

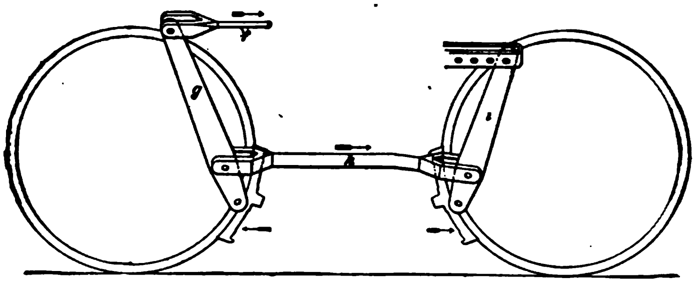

Fig. 36.

The arrangement of levers for passenger cars is like that shown in D of Fig. 32. It will be noticed that with the outside-hung brakes the connection *h* works under tension, whereas with the inside it is under compression.

To calculate the brake shoe pressure when the force exerted by the brake cylinder and the sizes of the levers are known, is a simple matter. It is done by calculating the leverages according to the rules laid down in Mechanics.

In Figs. 37 and 38 are given the sizes of the cylinder and live levers of the system respectively. The floating lever, is of the same dimensions as the cylinder lever, and the dead lever is is the same as the live. Starting with the system of levers shown

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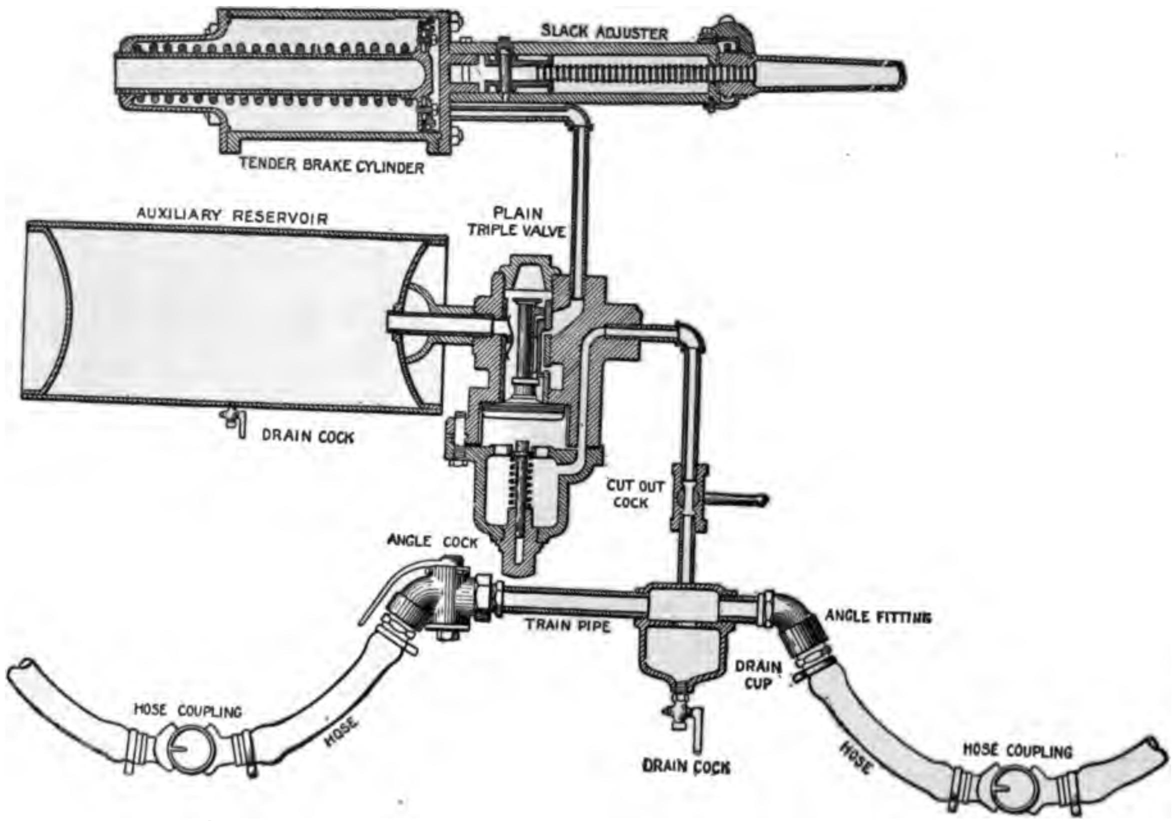

WESTINGHOUSE PLAIN TRIPLE VALVE AND CONNECTIONS.

in A of Fig. 32, suppose the brake cylinder to have a diameter of 8 inches and that the piston is working under a pressure of 30 lbs. per square inch. In this case we neglect the tension of the retracting spring in the cylinder head because it is such a small percentage of the whole. The pressure on the push rod *b* is equal to the area of the piston (50.26 sq. in.) multiplied by 30 or 1507.8 lbs. From the connection of *b* to that of *e* on the lever *e* is 9 inches. From the connection of *e* to that of *f* is 19 inches. Hence the pull on *e* is

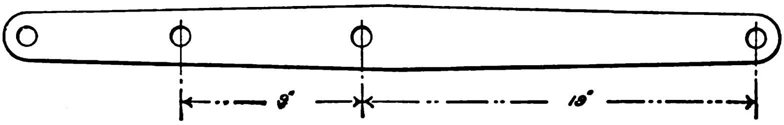

Fig. 37.

$$\frac{(19 + 9) \times 1507.8}{19} = 2222 + \text{pounds.}$$

The pull on *f* is

$$\frac{1507.8 \times 9}{19} = 714.2 \text{ pounds.}$$

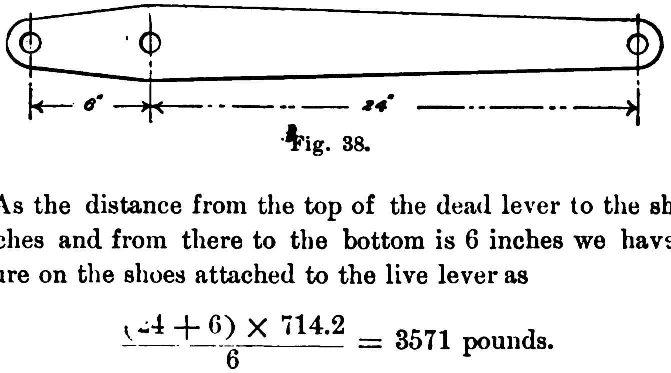

Fig. 38.

As the distance from the top of the dead lever to the shoe is 24 inches and from there to the bottom is 6 inches we have the pressure on the shoes attached to the live lever as

$$\frac{(24 + 6) \times 714.2}{6} = 3571 \text{ pounds.}$$

which must be divided between two shoes, giving a shoe pressure of 1785.5 pounds on each wheel.

The thrust on the rod *h'* is

$$\frac{24 \times 714.2}{6} = 2856.8 \text{ pounds.}$$

The pressure on the brake beam of the dead lever is

$$\frac{(24 + 6) \times 2856.8}{24} = 3571 \text{ pounds,}$$

or the same as that of the live lever.

It has been ascertained that the pull on e is 2222 pounds. As the floating lever has the same dimensions as the cylinder lever, the pull on f' is

$$\frac{2222 \times 9}{19 + 9} = 714.2 \text{ pounds.}$$

The pressure on each brake shoe on the car is therefore the same.

The lengths of the several levers are varied according to the weight of the cars. They should be so proportioned that with a full powered application of the brake the total shoe pressure should be equal to about 70 per cent. of the weight of the car.

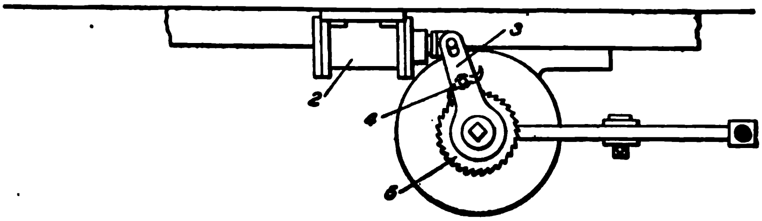

Fig. 39.

Brake Slack Adjuster. The object of a brake slack adjuster is to take up the slack produced by the wearing of the brake-shoes. The stroke of the piston is limited. Should the slack become excessive the piston of the brake cylinder might travel out until it struck the back head, before the shoes would touch the wheels. In order to avoid this the slack must be taken up or adjusted from time to time.

One method of doing this is to move the fulcrum pin of the dead lever.

It is desirable that the travel of the brake-cylinder piston should be kept as near 8 inches as possible. If it is more than this, a small amount of extra wear of the shoes would allow the piston to strike the head. When it is less the shoes are apt to be too near the wheels. The taking up of the slack automatically is done by an adjuster known as the McKee. It is illustrated in Figs. 39 and 40. The mechanism is very simple.

A reference to Figs. 32 and 35 will show that the floating lever turns on a fixed fulcrum back of the brake cylinder. It is evident then, that, if this fixed pivot is moved out from the cylinder, the brake connections will be drawn toward the center of the car. This slack adjuster does it. A pipe is tapped into the brake cylinder at a point that will be uncovered when the piston shall have traveled 8 inches. Air then passes out through this pipe (1) and enters the back end of the adjuster cylinder (2). The piston of this cylinder is then forced against a spring and the arm (3) turned so as to drag the pawl (4) over one or more of the teeth of the ratchet wheel (5). The ratchet wheel (5) is screwed on a stem (6), whose jaw forms the fulcrum of the floating lever (7). When the brakes are relaxed the piston of the brake cylinder moves back and uncovers the opening into the pipe (1). The air in the adjuster cylinder (2) then escapes into the atmosphere. Then the spring, which had been compressed, forces the adjuster piston back into position and turns the arm (3). The pawl (4) then engages in the ratchet and turns it. The thread on the ratchet thus draws out the stem (6) and moves the floating lever as desired.

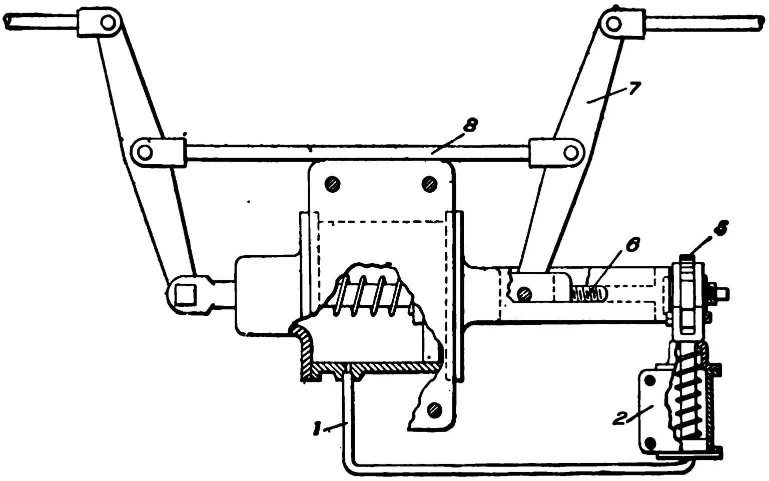

Fig. 40.

The adjuster is also used to shorten the cylinder and floating lever connection (8). This has the same effect on the shoes.

Driving Wheel Brakes. Brakes are applied to the driving wheels of a locomotive in two ways. One is the cam type illustrated by Fig 41. In this there is a cylinder bolted to the frame between the drivers. When air is admitted to the top of this cylinder its piston is forced down. This, in turn, pushes down the crosshead and cams. As the latter come down they force the shoes apart and against the wheels.

The other system is the outside equalized pressure driving brake, illustrated by Fig. 42. The cylinder is usually bolted to the back end of the frame. When air is admitted to the back end of this cylinder the long end of the lever (1) is pushed to the right. The short lower end is, at the same time, moved to the left. In this motion it pulls on the connection (2). Connection (2) is fastened to the center of a floating lever (3). The outer end of the floating lever (3) is attached to the brake shoe of the rear driver. The inner end is attached to the connection (4) which leads to the brake beam (5).

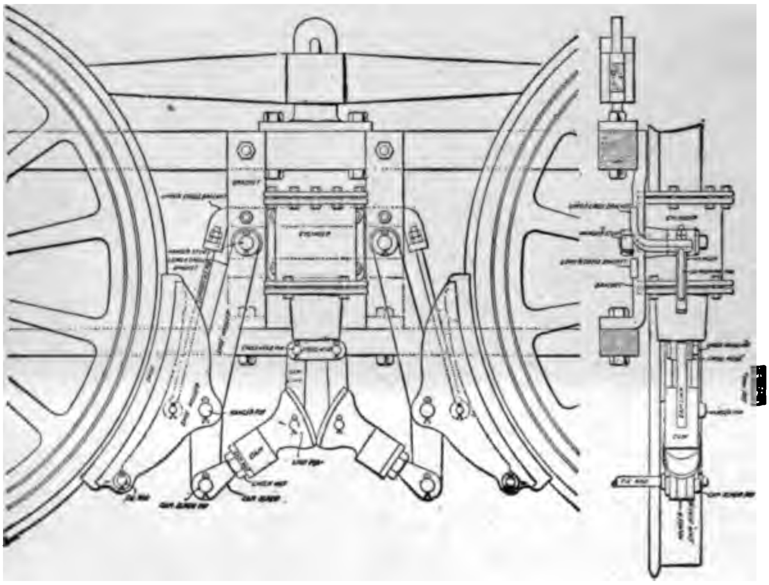

Fig. 41.

Thus if there is a pull of 1,000 pounds on the rod (2) there will be a pull of 500 pounds on the rod (4) and a pressure of 500 pounds on the back shoe. The rod (4) will put the same pressure on the front shoe.

When three or more pairs of drivers are to be braked the equalization of brakeshoe pressure is effected by an adjustment of the points of connection of the pull rods on the floating levers.

Thus, in Fig. 43 a diagram is given of the arrangement for four pairs of drivers. The rod A takes hold of the rear floating lever at the point *b* which is three times as far from *c* as it is from *a*. Hence, if there is a pull of 1,000 pounds on A, there will be a pull of 750 pounds on B and a pressure of 250 pounds on the shoe at *c*. The rod B takes hold of the second floating lever at *b'*, which is twice as far from *c'* as from *a'*. Hence, with a pull of 750 pounds on B there is a pull of 500 pounds on C and a pressure of 250 pounds on the shoe at *c'*. The rod C takes hold of the third floating lever at *b''*, which is midway between *a''* and *c''*. Hence, with a pull of 500 pounds on C there is a pressure of 250 pounds on the shoe at *c''* and a pull of the same amount on the rod D. The latter is communicated to the shoe at *c'''* through the brake beam at the end of the system.

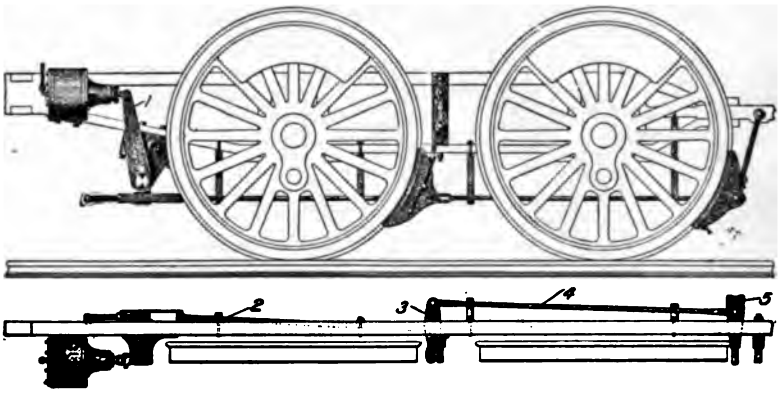

Fig. 42.

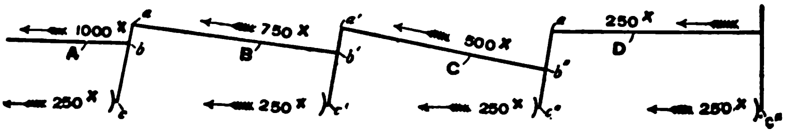

Fig. 43.

The High-Speed Brake. According to the Galton-Westinghouse experiments in England it was shown that the coefficient of friction of a brakeshoe against the wheel is less upon a rapidly than a slowly moving train. It is, therefore, possible to apply a heavier brakeshoe pressure when the train is moving rapidly than when its speed has been somewhat checked, without skidding the wheels. This is done by means of the high-speed brake. Where the high-speed brake is used the train-pipe pressure is increased to 110 pounds per square inch. By this device it is possible to exert a brake pressure of 125 per cent. of the weight on the wheels. This pressure is only used at the first application. It is gradually reduced as the train comes to a standstill. The mechanism employed is shown in section in Fig. 44. It is merely a leakage valve. The essential features consist of a piston (1) which is held to the upper end of its stroke by a spring (2). The spring (2) is adjusted to this position under a tension of 60 pounds per square inch of piston area for passenger cars and 50 pounds on engines and tenders. The slide valve (3) is attached to the piston stem. Brake cylinder pressure always has access through the connection (4) to the top of the piston (1). When this pressure exceeds that at which the spring is set, the piston is depressed and the port *b* in the valve opened to the port *a* in the case. Air then escapes from the brake cylinder. The auxiliary reservoir and brake cylinder pressures equalize at 85 pounds pressure. Hence, the first pressure of an emergency application is 85 pounds. This is gradually reduced to 60 pounds by the valve.

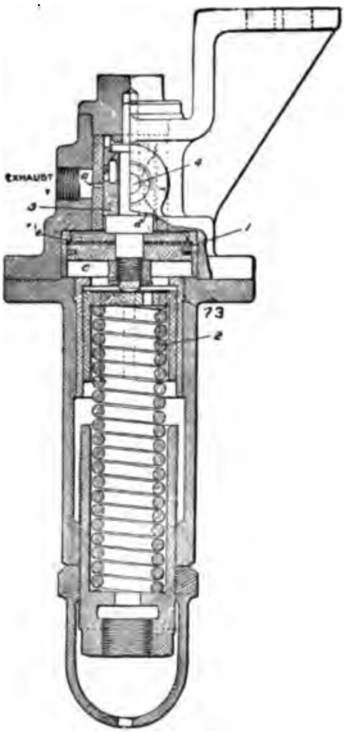

Fig. 44.

The only variations from the standard apparatus necessitated by the use of the high-speed brake are as follows: The high-speed valve is attached to the brake cylinder on each car; the engineer's valve has two feed valves attached, one adjusted to 70 pounds pressure and one to 100 pounds; the governor is of the duplex type, one being adjusted to stop the pump when a pressure of 90 pounds has been reached and the other when 110 pounds has been reached. One or the other parts of this duplicate apparatus is cut out according to which is to be used. This makes it possible to use the engine on trains equipped with either the high-speed or ordinary brake.

Train Inspection. All air brakes should be thoroughly inspected and tested before leaving a terminal. Before the engine is coupled to the train the pipes in the tender should be blown out in order to free them from dust. The hose connections throughout the whole length of the train must be made. All angle cocks are to be opened except the one at the rear end of the last car, which is to be closed. Connect the tender hose with that of the front car and open the angle cock at the rear of the tender. The engineer then moves the handle of the engineer's valve into the running position and proceeds to charge the train. After the train has become charged, the engineer must be signalled to apply the brakes. When the brakes have been applied they must be examined upon each car to see that they are properly applied. This having been ascertained, the inspector must signal the engineer to release the brakes, using the air signal from the rear car upon passenger trains. He must then again examine the brakes upon each car to note that each is released. If any defect is discovered it must be corrected and the testing of the brakes repeated until they are found to work properly upon each car.

Handling the Brakes. *Service Applications.* In applying the brakes to steady the train upon descending grades, or for reducing the speed for any purpose, be very careful not to make too great a reduction of pressure at the outset, as the speed of the train will be too quickly checked. Apply the brakes lightly at a sufficient distance from the stopping point, and increase the braking force gradually, as may be found necessary, so as to make the stop with one application, or at most two applications of the brakes.

With freight trains which are only partially equipped with the air brake, great care must be used to apply the brakes with only from six to eight pounds reduction, and to allow the slack of the train to be taken up before a further application is made, in order to prevent shocks, which may be serious.

In making a service stop with a passenger train, always release the brakes a short distance before coming to a dead stop, except on heavy grades, to prevent shocks at the instant of stopping. Even on moderate grades it is best to do this and then, after release, to apply the brakes lightly, to prevent the train starting, so that, when ready to start, the release will take place quickly. This does not apply to freight trains, upon which the brakes must not be released until the train has stopped.

Emergency Applications. The emergency application of the brakes must not be used, except in actual emergencies.

Cutting Out Brakes. The driver and tender brakes should always be used automatically at every application of the train brakes, unless defective, except upon such grades as shall be designated by special instructions. In such cases the driver brake may be cut out and used separately as a straight air brake. When it is necessary to cut out either the driver or tender brake, on account of defects, it should be done by turning the handle of the cut-out cock and leaving the bleed cock open.

If it becomes necessary to cut out the brake upon a car, while upon the road, it may be done by closing the cut-out cock in the branch pipe. When the brake has been thus cut out the cock in the auxiliary reservoir must be opened and left open upon passenger cars, or held open until all the air has escaped from the reservoir on freight cars.

Conductor's Valve. When it becomes necessary to make an emergency application of the brakes from the cars of the train, the conductor's valve is to be opened and held open until the train comes to a full stop and then must be closed again. This method of stopping a train is only to be used in cases of emergency.

Burst Hose. In the event of the bursting of a brake hose, it is to be replaced and the brakes tested before proceeding.

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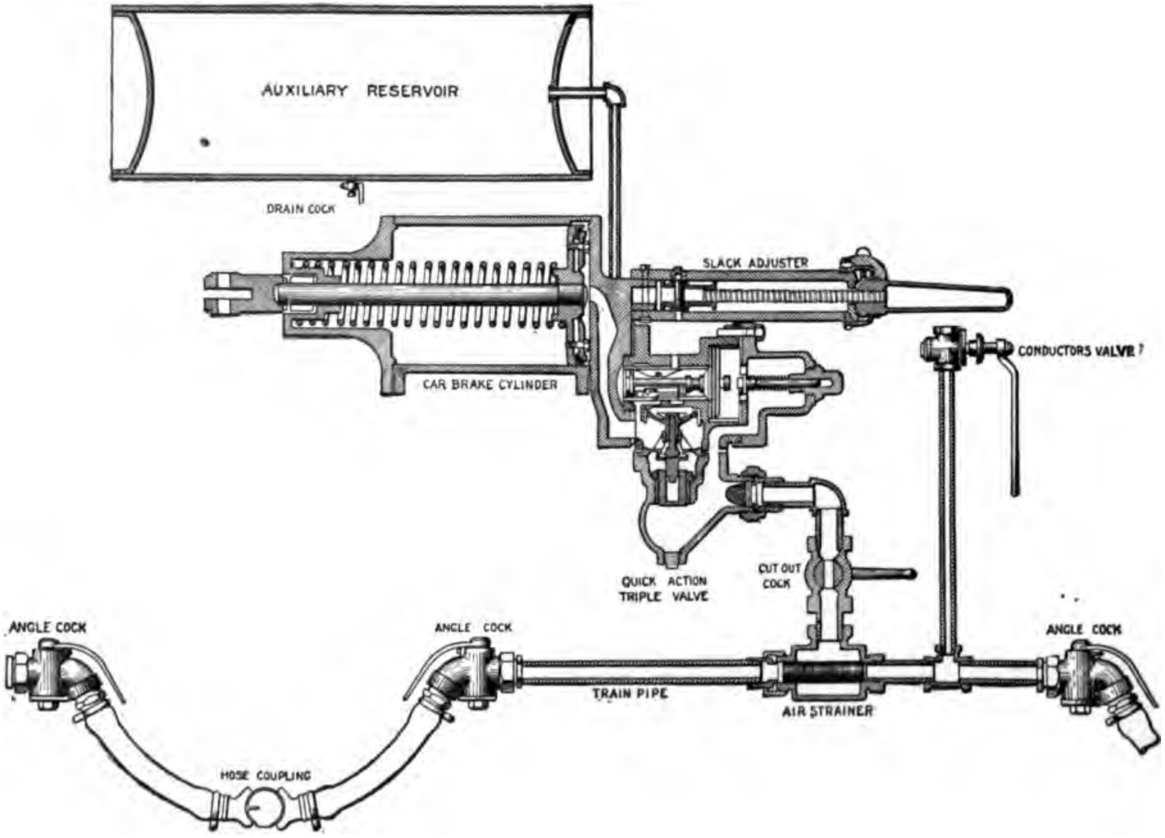

WESTINGHOUSE QUICK ACTION TRIPLE VALVE AND CONNECTIONS.

Pressure Retaining Valve. When this valve is to be used, the brakes upon the whole train should be tested at the top of the grade. Then the handles of all these valves are to be turned to a horizontal position. At the foot of the grade they are all to be turned downward again.

Double Headers. When two or more engines are coupled in the same train, the brakes must be connected through to and operated from the front engine. In order that this may be done it is customary to place a cock in the pipe just below the engineer's valve. This cock is to be closed on all of the engines except the one in front. The engineer's valves on all of these engines are then to be placed in the running position and a pressure maintained on them so as to enable their engineers to assume control of the train if necessary.

Detaching Engine or Cars. First close the angle cocks in the train pipes at the point of separation. Then part the couplings. This should always be done by hand. If the brakes have been applied, the cocks are not to be closed until the engineer has released the brakes.

Couplings Frozen. When couplings have become frozen they should never be pried apart. This will injure the gaskets. They should be thawed.

Train Breaking in Two. When a train breaks in two the emergency application of the brake stops the two sections. After the train has come to a standstill, first close the train pipe at the rear of the front section and signal to the engineer to release the brakes. Having coupled to the rear section observe the rules for the making up of trains. After the brakes have been released on the rear section the whole train should be tested before proceeding.

Miscellaneous Items. When an engine is to be coupled to a train it will be well for the engineer to make two or three light applications of the engine and tender brakes, before the coupling is made. The engineer's valve should be on lap when the hose is coupled. The application of the brakes reduces the auxiliary pressure and renders the engine and tender brakes less likely to stick on when the train is being charged. This is especially true where some of the brakes of the train have been applied with a light auxiliary pressure.

In applying brakes never make less than a five-pound reduction at the first application. The reason is that there is a leakage groove cut in the inside surface of the brake cylinders. This groove passes by the piston when it is in the release position. Its object is to allow any air that might leak into the brake cylinder from the auxiliary reservoir to escape past the piston without setting the brakes. When the brakes are to be applied, if a reduction of less than five pounds is made, the brakes will not be applied with sufficient force to move the piston past the leakage groove and the result will be that they will leak off at once. In this way air is wasted.

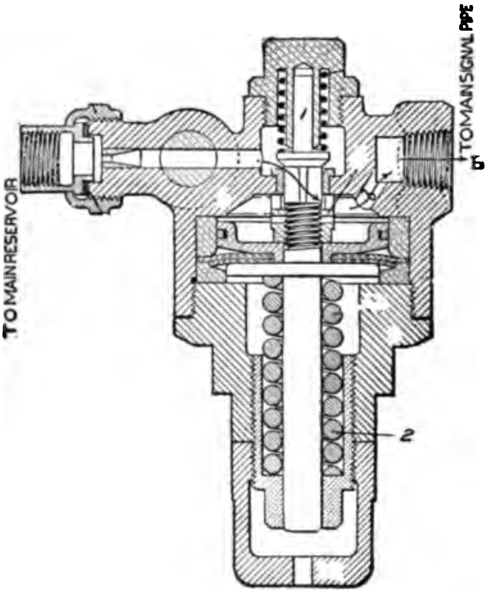

Fig. 45

When a reduction of 25 pounds has been made the pressures in the brake cylinder and the auxiliary reservoir will have become equalized. The maximum braking power has then been obtained and a further reduction of train-pipe pressure will not increase it.

When running down long grades with brakes held on with the retaining valves, recharging should be done on curves where the train binds and at points where the grade eases a little.

It does not take as much of a reduction to get a full application of the brakes when the retainers have been in use as it does when they are cut out.

When it is not necessary to use all of the retainers to hold a train those at the front should be used. This holds if the grade is short. In cases of long grades it will be well to change the retainers as the train proceeds using those on every other car. This avoids undue heating of the wheels.

Where hand brakes are to be applied in connection with the air brake it should be on the cars immediately behind those that are equipped with air.

An even travel to all of the brake pistons is very desirable. In case of an unequal travel the pistons with the long travel will be more easily released than those with the short. The reason is that the auxiliary pressure has been lowered to a greater extent by the former; hence a lower train-pipe pressure will produce release.

The Signal System. Closely allied with the air brake is the signal system. This latter is used to operate signals from the conductor to the engineer. It takes the place of the bell-cord and gong. Like the air brake it requires that a train-pipe shall run the whole length of the train. It is charged with air at a pressure of 40 pounds per square inch. The air supply is drawn from the main reservoir. The reduction of pressure is obtained by the use of the reducing valve, Fig. 45. This valve is similar in construction to the engineer's feed valve, Fig. 8. The description of the operation of the latter applies to this one. The plug valve in the upper left hand passageway is used to cut off the supply of air from the main reservoir when it becomes necessary to take down the parts of the valve for inspection or repairs.

Air from the main reservoir enters the reducing valve at the point indicated in Fig. 45. The air at the reduced pressure of 40 pounds leaves the reducing valve and enters the main signal pipe where shown. Near the reducing valve there is a tee in the signal pipe dividing it into two branches. One branch leads back to the train, the other leads to the signal valve.

The signal valve is shown in section in Fig. 46. Air enters from the signal pipe at the point indicated. It passes through a contracted port (1) into the space above the rubber diaphragm (2). From this space it goes through the passage (3) into the cavity (4) beneath the stem (5). The lower portion of this stem (5) is three-sided so that the air can pass freely up to where it seems to fit in the bushing (8). For a short distance at the top where the stem is round it fits loosely in the bushing. This loose fit permits the air to feed slowly into the large chamber (6). As the reducing valve is set to reduce the pressure to 40 pounds, it will only be a short time after air has been admitted before the pressure on the two sides of the diaphragm will be equalized at 40 pounds.

The main signal pipe runs the whole length of the train. In this respect it resembles the train-pipe of the air brake. On each car there is a discharge valve, Fig. 47. It is usually located above the door at the end of the car. The signal cord is attached to the eye (1) of the tee-shaped lever (2). The connection to the signal pipe is made at the point indicated. The air is prevented from escaping by the valve (3). This valve is held to its seat by the air pressure and the spring (4). The lever (2) is pivoted at the points (5) (5). If the cord is pulled so as to move the eye (1) in either direction, the lever (2) turns about the opposite pin (5) and being depressed at the center pushes the valve down and permits air to escape through the opening *a*.

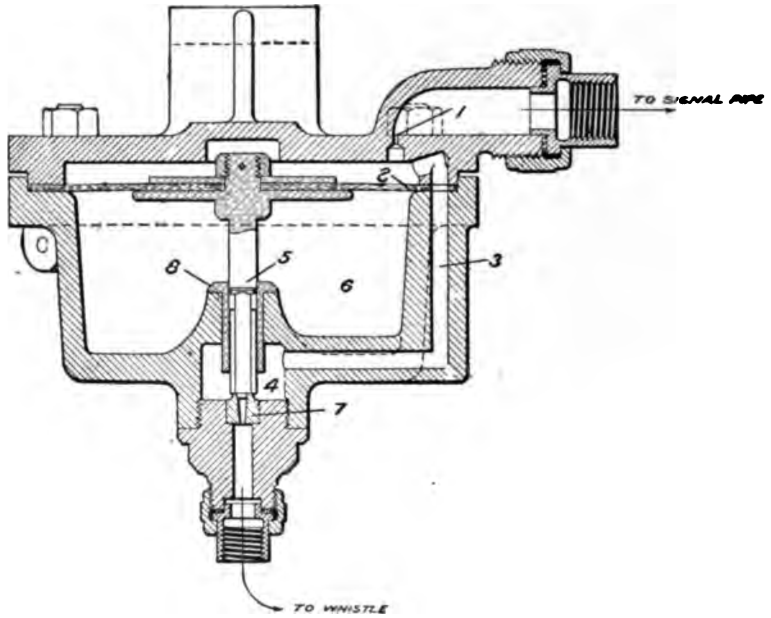

Fig. 46.

Returning to the engine: there is a small pipe leading from the bottom of the signal valve, at the point indicated, to a small whistle. This whistle is placed in the cab of the engine so that when it is sounded the engineer will hear it.

To sound this whistle the signal cord is pulled. This opens a discharge valve and starts a wave of reduced pressure through the whistle line. When this wave reaches the signal valve it is first felt in the small space above the diaphragm (2). As the pressure in the large chamber (6) cannot equalize quickly with the one above on account of the close fit of the stem (5), there will, for a moment, be a greater pressure below than there is above the diaphragm. This excess of pressure forces the diaphragm up. In this movement the diaphragm lifts the stem (5). In its normal position the stem (5) rests upon the socket (7). This closes the opening from the small space (4) to the whistle pipe. When the stem (5) is raised, it opens this passage and allows a wave of increased pressure to enter the whistle pipe. This wave moves on through this pipe until it reaches the whistle, which it sounds.

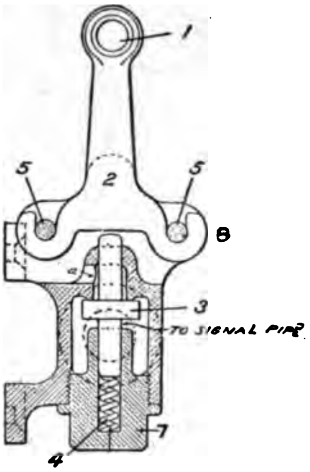

Fig. 47.

In about two seconds the pressures on either side of the diaphragm (2) will have equalized and the stem (5) have resumed its normal position as shown in the illustration.

When the whistle is to be sounded the discharge valve should be held open for about one second. It should then be closed for two seconds after which it may be opened again. If the whistle does not respond to a pull of the signal cord, the reason may be that there is a dirty strainer on the car where the branch to the discharge valve couples to the main signal pipe; the small port (1) of the signal valve may be stopped up; there may be too loose a fit of the stem (5) in the bushing (8); the diaphragm (2) may be baggy or have a hole in it; or the bowl of the whistle may be closed or improperly adjusted.

If the signal cord is pulled a second time without a sufficient lapse of time between the first and second pull the whistle may not respond to the second pull.

If dirt gets beneath the valve (1) of the reducing valve of Fig. 45, it will allow main reservoir pressure to get into the signal line. When this occurs, the whistle will be apt to sound when brakes are released. The reason for this is that when brakes are released the main reservoir pressure is slightly reduced. This permits a wave of reduced pressure to come up to the port (1) of the signal valve and cause the diaphragm to rise, thus sounding the whistle.

The pressure in the signal line can be determined without the use of a special gauge. First stop the pump, then open the bleeding cock on the main reservoir. As soon as the pressure has fallen to a little below that of the signal pipe the whistle will sound. The pressure will then be indicated by the red hand of the air brake gauge. The whistle is sounded because air flows from the signal pipe into that leading to the main reservoir.

Pressure may be increased in the signal line by tightening the spring (2) beneath the piston of the reducing valve, Fig. 45. It may be lowered by slackening the spring.

The reason why the whistle will not respond to a pull of the signal cord when the diaphragm (2) of the signal valve is baggy is that the expansion of the air of the lower chamber (6) is taken up by the bagginess and does not lift the stem (5).

As in the air brake all parts should be kept clean so as to insure a certain and efficient working of the apparatus.

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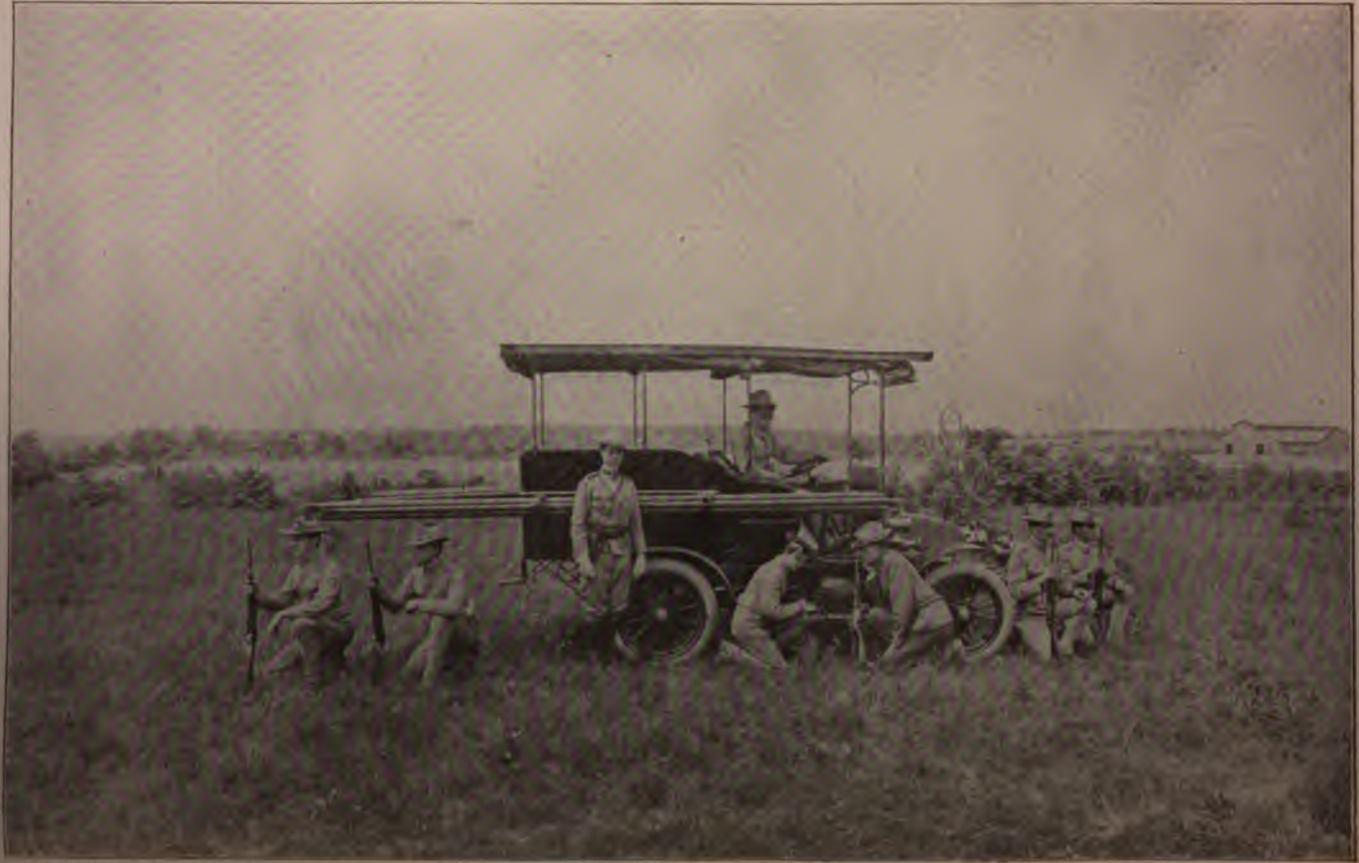

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USE OF THE AUTOMOBILE IN WAR.—AUTO-TELEGRAPH CAR OF THE SIGNAL CORPS, U. S. ARMY.

A Scene during the Manœuvers of 1904 on the Historic Battlefield of Bull Run.

AUTOMOBILES

As a device for saving time and distance, the motor vehicle bids fair to eclipse all others and to prove itself one of the greatest inventions of an inventive age. Its motor will, in time, be built cheaper than a horse can be grown, its transmission gear will cost less than a harness, while its body need cost little, if any more than similar parts of horse vehicles. Rapid as has been the growth, and astonishing as are the results shown to-day by this class of vehicles, it is evident that this is but the beginning and that in the very near future, a development and growth far beyond present conception is sure to come.

The motor vehicle is not a new invention. It is the father of the traction engine and of the locomotive. It is one of the devices earliest sought for but latest to be practically and popularly worked out; and few problems of greater severity have been presented to engineers. Its need has been felt everywhere, for we spend our lives exchanging what we have for what we desire and this requires transportation. At both ends and often between ends of the route over which the exchange is made animal power is used and here the auto is needed and will be used with great saving. The director of the United States Road Inquiry Bureau says the cost of moving tonnage 1250 miles by steamships, 250 miles by steam cars, or 25 miles by electric cars is no greater than the cost of moving tonnage 5 miles by animal power on the common roads—a proportion of 1 to 5, 1 to 50 and 1 to 250 in favor of mechanical transportation against the horse; and yet with these figures before them, capitalists build larger steamships and better railways in an attempt to save an additional slight percentage on these already cheap methods, while the horse has continued to draw the same old wagon at a snail's pace over abominable roads, simply because heretofore the motor vehicle has not come into use.

On the other hand while this has been the general condition, there have always been attempts to secure better results. Pioneers have exerted themselves to build mechanical motors for use on the common roads in the face of the great chances of failure and the derision of the world. To them we owe the progress that has been made.

HISTORY

Nearly three centuries ago a German at Nuremberg proposed to drive vehicles "2000 paces an hour by means of springs," and similar carriages were proposed by others. In 1759 Dr. Robinson called the attention of Watt to the possibilities of steam vehicles. In 1763 to 1769 Cugnot, a Frenchman, designed and built with the assistance of the French War Department, a steam-propelled gun-carriage and in 1797 a four-passenger tricycle capable of four miles per hour. In England a practical result was shown in 1781 by Murdock and in America by Oliver Evans in 1804. These were mostly steam vehicles, although gunpowder engines much resembling gas engines were among the earliest proposed. Compressed air was also used, notably by Mann in 1822 and others.

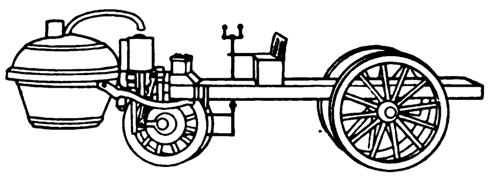


Fig. 1. Cugnot's Steam Carriage, 1769.

The first half of the 19th century was marked by many attempts at motor road-locomotion and many vehicles, particularly omnibuses for public hire, were made and operated between 1820 and 1844 by Hancock, Gurney, Church, Fisher, James, Squire, Russell (constructor of the Great Eastern Steamship) and others. These vehicles were operated with success on regular schedules over regular routes, were much liked by travelers and were crowded with passengers, and they bade fair to inaugurate the horseless age and bring in an era of cheap transportation.

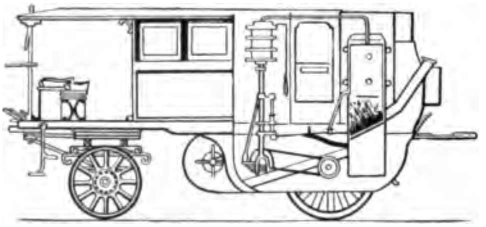


Fig. 2. Hancock's Steam Carriage, 1835.

Public opinion, however, was not with these vehicles. Horse users and stage drivers were very bitter against them. The Road

Trustees imposed unjust and discriminating tolls and the ill feeling and prejudice finally resulted in restrictive laws prohibiting a speed faster than three or four miles per hour and compelling a man to precede the vehicle with a red flag. The result was that the industry died and did not again exist in England until the passage of the "Light Locomotives Act" in 1896, a loss of more than 50 years and of millions of dollars that would otherwise have gone to the English nation. In the meantime the locomotive was developed to run on special rights of way and the traction engine plodded at a snail's pace whenever it used the highways.

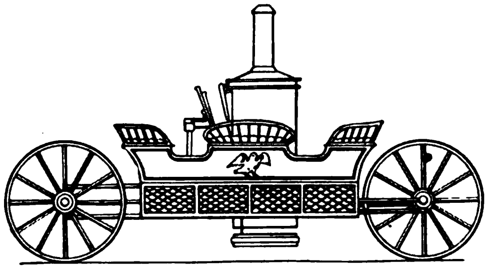


Fig. 3. Fisher's Steam Carriage, 1840.

Occasional Experiments. Occasional inventors made experiments from time to time in France, Germany and America, but for one reason or another none of these found favor In 1860 to '62 Lenoir, a Frenchman, designed a gas engine of the four stroke cycle type and applied it to a motor vehicle. Ten years later the elder Bollee built one or more steam vehicles which received some use on French roads. About 1876 Fawcett, at Pittsburg, built an omnibus using a Brayton internally fired engine burning liquid fuel. Ten years later Copeland in America fitted small, light steam motors to bicycles and tricycles with some degree of success, while Daimler and Benz in Germany about the same time applied gas engines of the four cycle type successfully to motor vehicles.

The next ten years marks the beginning of the present motor vehicle industry. In Germany, Daimler developed the small high speed motor which is admittedly the predecessor of present day practice. Benz, his countryman, confined himself more to the application of engines resembling stationary engines, and while very successful, so far as quantity of vehicles made and service rendered is considered, did not influence the industry as did Daimler whose inventions were taken up in France about 1892 or '93. In America, occasionally experimenting since 1886, the Duryea Bros. began continuous work on gasolene vehicles in 1891, which work unlike many experiments, has been carried forth continually since. In 1893 Sturgess, of Chicago, exhibited an electric vehicle at the Columbian Exposition.

In 1894 and 1895 very successful road contests were held in France and attracted the attention of the civilized world. These were followed by several automobile events in America, the first of which was the Times-Herald contest at Chicago.

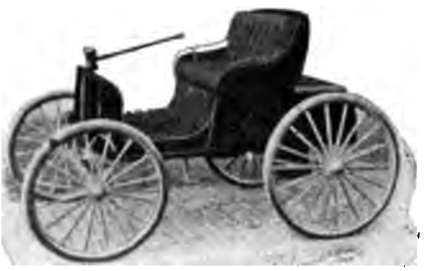


Fig. 4. Five Horse-Power Runabout, 1896 Model.

Pioneers. It is difficult in a historical account, to set a proper value on the various experiments and attempts made in different parts of the world, for no one can say what bearing or influence any particular experiment may have had on the work of later builders. It is eminently proper, however, to give credit to work that has continued with little or no interruption into the present period; to work that showed marked pre-eminence either by the results accomplished or by the means and mechanism used, and to work that has in any way stamped itself upon present practice to a noticeable extent. Judged by these standards the pioneers in the electric vehicle field were Sturgess, 1893, Morris & Salom, 1894 and '95, Woods, 1895 and Riker, 1896. In steam vehicles the work of Copeland (given considerable prominence through the Cycle publications), was followed about 1896 and '97 by the successful steam carriage of Whitney, which was the direct predecessor of the product of the Stanley Bros., first introduced to the public at Charles River park, Boston, Mass., in the fall of 1898. In gasolene vehicles, the

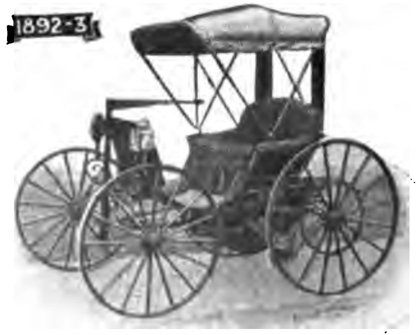


Fig. 5. Two and One-Half Horse-Power Phaeton. 1902 Model.

first Duryea finished in 1892, and the second one finished in 1893, both of the single cylinder variety, were followed in 1894 by the double cylinder carriage which won the Chicago Times-Herald contest. The first single cylinder Haynes vehicle was finished in the summer of 1894, followed late in 1895 by the second Haynes, a two cylinder vehicle, the first of the opposed cylinder type. In 1896 the first Winton made its appearance, while in this same year more than a dozen Duryea vehicles were completed and the new industry was fairly started on its way.

Little Interest. Progress was at first slow both in America and England, although more rapid in Germany and France, due to the favorable roads, liberal laws and greater interest among experimenters and capitalists. In America, the downfall of the bicycle business destroyed much of the financial confidence necessary to the development of the new industry and interest lagged until the steam vehicle shown by the Stanleys in 1898, and offered to the public by many makers at a low price, began to be put on the market in a large way and extensively advertised. It met with an enthusiastic reception, was not protected by patents and was therefore largely copied by other makers, with the result that it seemed to have the field to itself. The steam vehicle, as then constructed, however, fell from popularity, even more rapidly than it attained it. The great complexity, the delicacy of the many parts, the small wheels, the inadequate tires, the short wheel base, together with many other features of similar character, all contributed to the downfall of this promising, popular carriage.

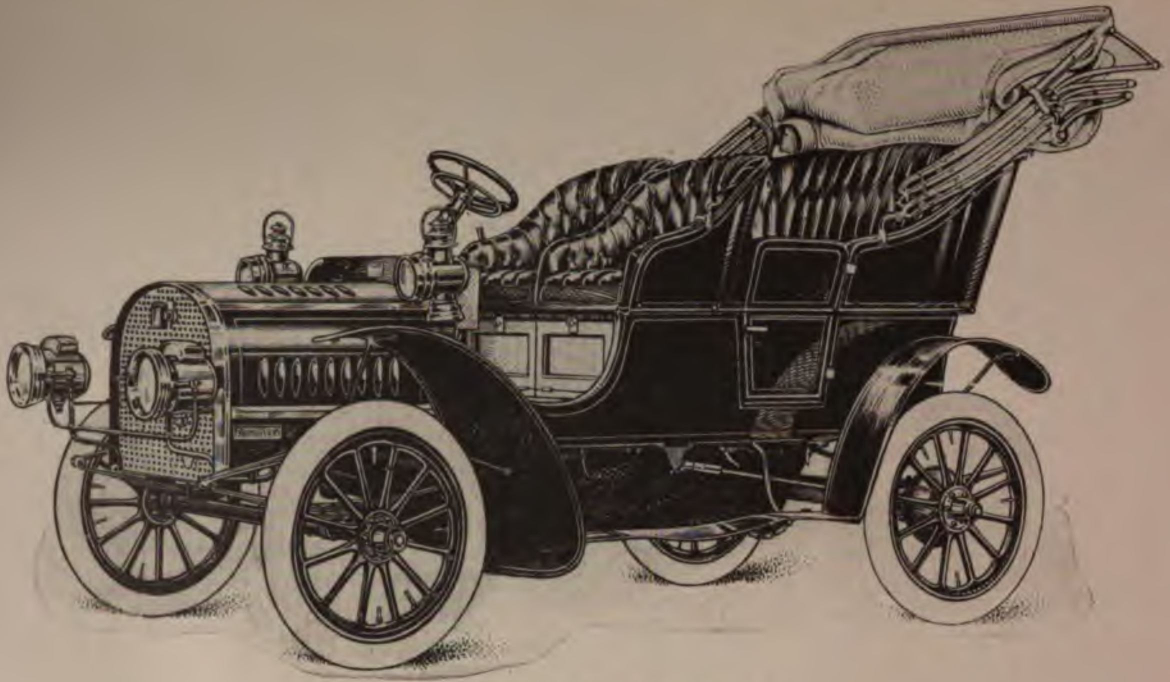
In the meantime, the electric vehicle was being exploited by large capitalists in the large cities for public service, and cab companies, overcapitalized, sprang up in many places, doomed to disappointment because of the lack of experience and the fact that their vehicles had not been proved by years of service to be what was needed for their work. This adverse experience did much toward holding back the adoption of the electric vehicle by many to whom it would have been of great value, and hurt the business generally.

Steady Growth. Across the ocean Serpollet, beginning about 1886, had been slowly developing a promising steam vehicle while one or more experimenters were developing the electric. The gasolene vehicle, pushed by many, made most rapid progress. In America also, it made progress conservatively but steadily. Fathered by mechanics, rather than by capitalists and promoters, it was steadily improved, its defects and limitations were studied, it was sold at a price consistent with good quality, and although slow in coming to its recognition, the certainty of that recognition was made more sure by the very length of the period devoted to its development.

This slow growth gave opportunity for experimentation and brought into existence most of the valuable features of present day autos as well as some features that will undoubtedly be used in future years, although not recognized at their true value now. Thus the first Duryea vehicles, finished in 1892 and 1893, had front axles fitted with wheel pivots or steering heads as close to the wheels as possible, and these pivots were inclined, so as to strike the ground at the bottom at the point of contact of the wheel, which arrangement secures a steering that is practically irreversible, that steers very easily and permits running over obstructions with no shock on the steering parts or tendency to deviate from a straight line—facts which are not yet fully known by constructors and therefore not made use of to a large degree. They employed a three point rear frame with motor and transmission mounted closely together upon it, double side-chain drive with balance gear in the counter shaft, electric ignition, spray carburettor, motor lengthwise the body and many other devices that have since become standard practice.

This period of the history of the gasolene vehicle was not influenced by foreign practice and was more truly American and better suited to the American roads and conditions than many present-day constructions, although at that time the full importance of ample power was not recognized, mechanics were untrained, and many vehicles were incapable and unreliable.

Steam Decadence. About the time of the decadence of the steam vehicle fad, 1901, two vehicles of particular importance began to attract attention,—the Olds and the Knox. The Olds is interesting because of the distinctive shape of the body which resembled a toboggan at its forward end, the shape of the springs, which were fastened at one end to the body and at the other to the axles, and the generally light and simple appearance. This vehicle was put out in large numbers at a moderate price, was quite successfully imitated by many other concerns, and was for a time the representative American type, and recognized as such in many parts of the world. The Knox equally



SURREY TYPE OF RAMBLER AUTOMOBILE
Thos. B. Jeffrey & Co.

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ASTOR, LENOX AND
TILDEN FOUNDATIONS
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deserves mention because of its system of air cooling, which was really the only successful form for a considerable period. Many attempts had been made at air cooling, but most of them had been failures for one reason or another; but Knox, by his firm belief in the efficiency of threaded pins screwed into the walls of the cylinder, including the head and valve chambers, demonstrated the practicability of this system, and although standing alone, after others had abandoned air cooling, for all except the smallest sizes, has been followed by a great variety of very efficient air cooling methods.

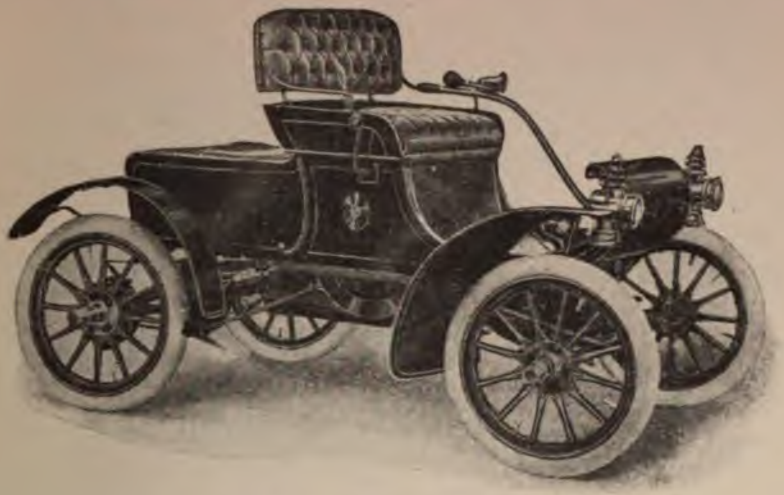


Fig. 6. Standard Oldsmobile Runabout.

Foreign Influence. Abroad, the gasolene vehicle was turned out in large numbers, and was seen, tried, admired, and purchased by the vast number of American tourists, who, too busy at home to even look at an auto, became willing converts abroad and spent their vacations enjoying the good roads of Europe and the new method of locomotion at the same time. The earliest vehicles of Daimler had been fitted with a motor under the seat, but in order to secure greater accessibility he soon transferred this to the front of the vehicle, where it was enclosed in a box, and this practice has prevailed abroad to the present day and has been followed very largely in America through the influence of the tourists.

The splendid foreign roads with their hard surfaces and easy grades permitted the use of small wheels, of mechanism close to the ground and required so little traction that no great weight was needed upon the driving wheels; while favorable speed laws and road conditions permitted the use of high powers and the attainment of railroad speeds.

American Conditions. In America, where the majority of the roads are bad, the things demanded of a motor vehicle are considerably different, and they are not properly met by foreign designs so prevalent to-day. Rough roads require large wheels, ample clearance under the body, protection of the mechanism from mud and dust, great weight on the propelling wheels, large wheels that will roll over rough places easily, a simple and light mechanism that will stand the rough service with the minimum of repairs. Many other similar features are essential to meet the road conditions and also the needs of a thoroughly practical people, rather than those designed simply to serve as a sport of a leisure class. It seems evident, therefore, that many of the features first developed in America, to meet American conditions, and more or less largely abandoned in favor of foreign design, will eventually become standard American practice, because best suited to American needs. Fluctuations are, of course, apparent in the development of any new industry, for, in their inexperience, the buying public is apt to grasp at new designs as the solution of its difficulties, without really knowing whether the new is better or as good as the old, but as a wider variety of styles is seen in use, these fluctuations will become less pronounced until finally purchasers will have a large variety from which to select and particular needs rather than present fad will more largely influence the selection.

Present Types. Present-day autos can be divided into a wide number of classes in addition to the three general classes, electric, steam and gasolene, already considered. In electric vehicles, there is but little variation except in the shapes of the body, although some vehicles are equipped with two motors, others with but one, and batteries vary somewhat in arrangement, kind, and size, while controllers and fittings exhibit the designers' preferences.

The electric vehicle is of limited range and well adapted to city use for elderly people or ladies. Like the steamer, it seldom needs attention on the road and generally gets home if the batteries are not exhausted. The batteries, like the steam boiler, are the objectionable feature, for they are quite complicated, heavy, subject to chemical change; also to physical change, such as buckling, loosening of the active matter from the plates and leakage, spilling or evaporation of the electrolyte. The density of the electrolyte needs watching to secure best results, and the batteries should always be kept charged.

Steam Vehicles. These are considered well-known because they employ steam engines and boilers and do not ordinarily use a speed changing device. The White steamer uses a tubular generator in which the water enters the top and is converted into superheated steam by contact with the hot metal. No water is carried in the boiler, so little time is required to get up steam, and an increased supply of water is met by an increased fuel supply, resulting in increased quantity of steam. With the steam vehicle, pressure is required to make the fuel mix with air, and the burner requires more or less attention. The piping, pumps and stuffing boxes must be known to be in good order, and loss of power is usually attributed to a leak or to improper fuel and water supply.

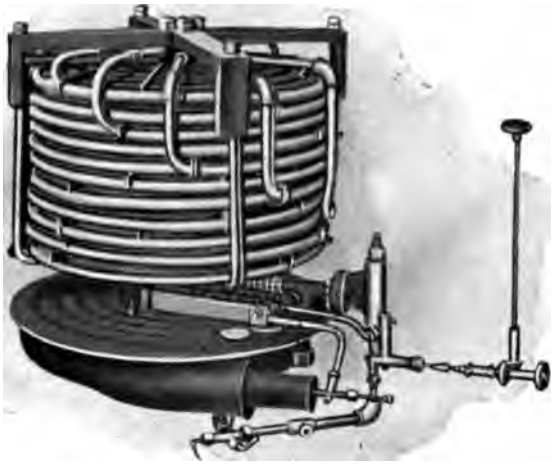


Fig. 7. White Tubular Generator.

In the Stanley steamer, the motor is geared direct to the rear axle, instead of being connected by chain as in most other forms. The light weight of the Stanley steamer, and also the Baker electric vehicle contribute much to the high efficiency shown by these light carriages.

Steam vehicles differ principally in the type of boiler, there being two general kinds, the fire tube, of which the Stanley is best known, and the flash or generator, of which the White is the principal exponent. Burners, engines and their arrangement vary also.

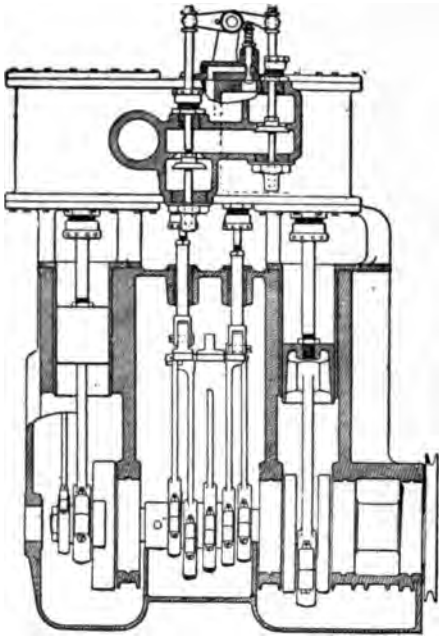


Fig. 8. Diagram of White Steam Engine.

Variations. Since, however, the majority of present day autos are gasolene vehicles, it will suffice to describe in them, most of the details that enter the auto of to-day. Besides the variations in the body, such as single or double seat, folding seat or detachable, open, with top or enclosed, side or rear entrance and many similar variations, there are two kinds of motors, two-stroke cycle and four-stroke cycle; two varieties of cooling, air and water; three locations of the mechanism, front, midway and rear; several forms of transmission, such as belt, friction, chain, planetary gear, sliding gear, individual clutch, and many variations including combinations of hydraulic and electric systems. There are two largely-used methods of ignition, with several accepted sources of electric current, viz., the jump and the contact spark; with primary batteries, storage batteries, magnetos and dynamos for supplying the electricity. Since, however, there are several hundred parts required to make up a motor vehicle, it seems best to describe these parts under various headings rather than attempt a general description which cannot be other than confusing.

The motor vehicle is commonly considered as a combination of a motor and vehicle with such other parts as are needed to make the combination operative, and in this connection the motor is described first. Since, however, vehicle motors are but modifications—us light and of high speed—of motors long used for stationary work, it will not be necessary to include here so complete a description as would otherwise be the case, since this information can be obtained in text books treating directly of the motor.

THE MOTOR

The theory of the gasolene motor is that a mixture of air and gasolene vapor is drawn into the cylinder of an engine and ignited, after which the pressure, due to the expansion, is caused to perform work in propelling the vehicle. The essential parts are the *cylinder*, *piston*, *crank shaft*, *fly wheel*, *inlet* and *exhaust* devices, *ignition* arrangement, *vaporizer*, and means of *control*, together with important incidentals, such as lubrication and means for cooling..

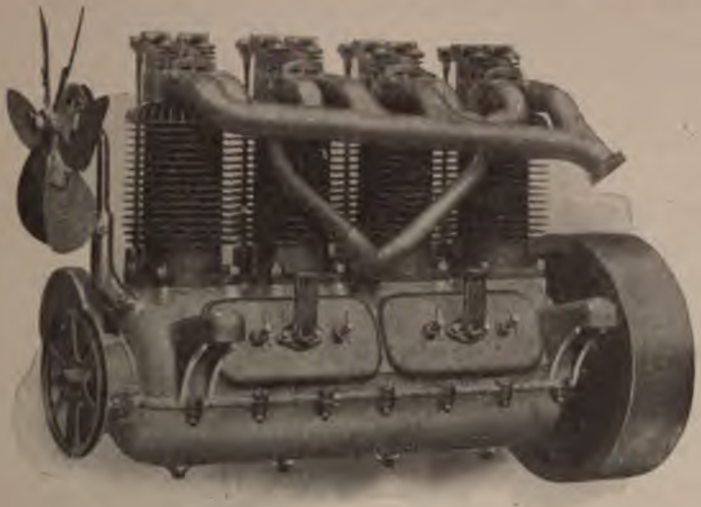


Fig.9. Four-Cylinder Gasolene Engine.

Cylinder. The cylinder of the engine for auto use is usually from three to six inches bore, with stroke sometimes longer, sometimes shorter, but quite generally the same as the bore. Cast iron is the usual material from which the cylinders are made, and provision for cooling, such as a water jacket, is usually cast integral with the cylinder, although quite frequently affixed in the form of a sheet metal jacket on pins after the cylinder is machined. These cylinders may be attached to the crank case or formed with part or all of the crank case in one piece. Each method of construction has its followers and each has its advantages, according to the design of motor, crank shaft and similar parts. In motors of the type first used on DeDion tricycles, the flywheels were disks enclosed in the crank case and forming the crank sides, and since they practically filled the crank case, it was necessary that this be made in separable halves. The separation was in the plane of the crank rotation, which permitted each half of the case with its long, hardened and lapped but nonadjustable bearing, to be removed by sliding off opposite ends of the crank shaft. The cylinder was held to this case after the halves had been brought together, by screws or bolts. In many instances the head of the cylinder was held against the cylinder end by the same bolts, so that the cylinder was actually clamped between the head and the case. This design employed a cylinder open at each end, making a quite simple casting and facilitating machining.

Other cylinders are built with a simple head screwed in position, and with the ports on the sides of the cylinder instead of forming part of the head. Air-cooled cylinders are most frequently provided with circular flanges spaced one to three times their thickness apart, and rising above the cylinder wall from two to ten times their own thickness. In some cases these flanges are of sheet metal of great conductivity, as copper, forced tightly upon the smooth wall of the cylinder, or they are of smaller pieces attached by calking, clamping or other effective form of contact in or to the cylinder wall. It is essential for good results, that the cylinder should be true, particularly when hot, for if it is not truly round, and practically parallel throughout its length, the piston rings will not fit, and will not retain the gases which, leaking past the piston, leave their heat in the cylinder walls, blow away and burn up the lubricating oil, and cause excessive heating, pounding, loss of power, premature ignition and even cutting of the metal surfaces, destroying both piston and cylinder.

Valve Ports. The most common arrangement of the ports employs a pocket or passage at one side of the cylinder head in which the valves and frequently the sparking parts are placed. The exhaust valve is the nearest the crank shaft, with its stem extending toward the crank shaft where it is conveniently operated upon by the cam on the half time shaft which lifts the valve every second revolution, as is required in a four cycle engine. The inlet valve is placed with its stem in the same axial line but projecting in the opposite direction, and is held closed by a spring and opens by the suction of the piston. By this arrangement the cool incoming charge strikes the exhaust valve and sparker parts and much reduces the temperature. Burnt gases are carried out of the pocket, leaving a fresh combustible mixture therein which contributes to certain ignition.

Recent designs have employed double cam shafts on opposite sides of the motor with valve pockets likewise on opposite sides, the inlet valve being mechanically opened, and arranged the same as the exhaust valve. These double pockets increase the wall of the compression space and therefore the loss of heat, and lessen the economy.

To avoid this increased wall surface of the compression space, many constructors now place the valves in the head of the cylinder with their stems projecting away from the crank shaft, and operate the valve by rocker arms, or place the cam shaft beyond the cylinder head and drive it by chain and sprockets instead of gears.

Whatever the form of cylinder and fittings, it is essential that there be good compression, or, in other words, that the contents of the cylinder be not allowed to escape. To test the compression, turn the engine by hand until the piston comes against the contained gases as against a strong spring, and judge by the length of time that this resistance continues as to the rapidity of the escape. A tight cylinder properly lubricated ought to resist a pull on the starting crank for a minute or more and should require considerable effort to force the engine past the compression. The operator should distinguish between high compression and good compression. If the clearance at the head of the cylinder on the compression dead center is small, the engine is known as "high compression" and if turned quickly, the resistance will be high, even though the valves or piston rings may be leaking and the compression therefore not good.

Faulty Compression. If the compression is faulty the escaping gas can usually be heard, announcing its escape by hissing. The point of escape must then be found and will usually be at the exhaust valve, for the inlet valve, being kept cool by the incoming charge, seldom needs attention. If the passages can be opened, a candle flame will, by its flickering, indicate the leak, to remedy which the valve must be removed and ground. Grinding a valve consists in oscillating it upon its seat until the high spots are worn down, so that the valve bears equally and fully all around, thus making a tight joint. Flour emery mixed with oil is usually used, but a tighter and smoother job may be secured by finishing with powdered glass or sharp sand like the powder from the water-trough of a common grindstone.

If the leak is around the piston rings, new rings or newly fitted pistons may be needed. To avoid damage to the piston or cylinder, the operator should stop immediately if the engine begins to pound, smoke, or lose power, and he should determine the cause of the trouble before proceeding. Lack of water, a broken belt on the cooling fan, or lack of oil will usually be found causing the trouble.

Piston. The piston is the moving part which fits into the cylinder and against which the explosive pressure is exerted by the burning gases. Pistons are usually from one to two times their own diameter in length and are provided with two to four rings at the head and and occasionally with one ring at their open end. They are unlike steam engine pistons in that the pressure is taken on the head end only and that they serve as cross heads, having the connecting rods attached to wrist pins fitted generally about midway the length of the piston. This wrist pin ordinarily passes through the piston walls, lugs or enlargements being provided interiorly therefor. The wrist pin is usually fixed in the piston and the end of the connecting rod has a bearing thereon, although in some cases the pin is fixed in the end of a rod and takes its bearing in the piston, by which means a larger bearing surface is secured, and removable bushings are fitted in from the out-

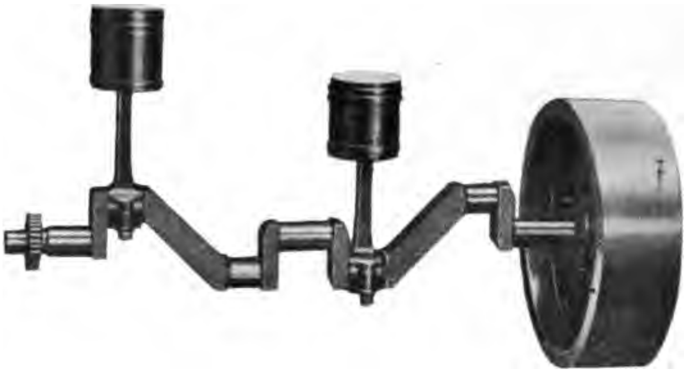


Fig. 10. Pistons and their Connections with Crank Shaft.

side of the piston, as in Rambler autos. The head of the piston is quite commonly flat, but is frequently concave as in the Duryea, or convex as in the Autocar, and these forms are stronger and lighter than the flat head. The interior of the head is sometimes provided with radiating webs or pins as in the Frayer-Miller. The piston rings are usually of cast iron machined to a diameter larger than the diameter of the piston and then cut so as to be compressed to the cylinder diameter, which leaves them with a tendency to open and causes them to fit closely to the cylinder wall. They should be fitted carefully to their grooves in the piston, and it is particularly important that their sides be carefully fitted to the sides of the groove, so as to make a gas tight joint and prevent the escape of the gas under the ring. Two rings are often fitted in a single groove with their joints in different positions, and a third ring is sometimes placed underneath, which also serves to close the joint. Various joints are used, but a plain cut of 45 degrees or two perpendicular cuts from opposite sides, each cut being on opposite sides of a dividing line, are sometimes used, making a lap joint that is regarded as superior to the diagonal joint. Care should be taken in removing and replacing piston rings not to spring them harshly, for they will seldom return to their original shape if much abused, and if they do not fit the cylinder they will not serve their purpose properly.

Connecting Rods. The connecting rod attaches the piston to the crank shaft, and since auto engines are desired to be compact, these rods are 1½ to 3 times the piston throw. They are generally of I-beam section, so as to resist the alternating stresses to which they are exposed, but are frequently of U-section, particularly in horizontal engines, so that they may catch oil and direct it into the bearings and thus assist in efficient lubrication. Connecting rods are usually made of forged steel, but steel castings and bronze castings are sometimes used. The wrist end is very frequently solid and fitted with a bushing for the wrist pin, but in many forms this end is provided with a lug at one side, split and drawn together for adjustment by a screw. Occasionally a removable cap is fitted. At the crank end the removable cap is the more common construction. Sometimes this cap is hinged at one side and

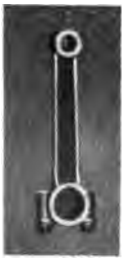


Fig. 11. Connecting Rod.

adjusted by a single screw at the other. Bushings of Babbitt metal are very commonly fitted at the crank end.

Crank Shaft. The crank shaft is usually of a high grade steel and is frequently hardened and ground. Bearings are provided at short distances apart, frequently between all cylinders, and seldom if ever farther apart than is required to bring two cylinders as close together as possible. This large amount of bearing surface contributes to long life, and also supports the crank and thus prevents danger of damaging the bearings by strains or damaging the shaft. A wide variety in shafts is found, depending upon the type of engine, the number of cylinders, the class of bearings, and the objects of the designer. Where ball bearings of the nonadjustable type are used, the crank shafts have been built up in short pieces, so as to permit putting the ball bearings into position, but this method is not very common. Shafts are frequently made hollow, both in the shaft proper and in the crank pin, for by so doing nearly one fourth the weight can be saved, with little decrease in strength.

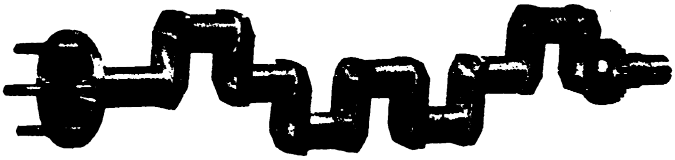


Fig. 12. Crank Shaft.

The common method of attaching the fly-wheel to auto crank shafts is by means of a flange integral with the crank instead of keyed on, as in most other engine practice. The web of the fly-wheel is bolted to this flange by an ample number of bolts to hold it securely and yet permit easy removal. The saving in space lengthwise of the crank shaft makes this method of particular value in a vehicle like the Duryea, where the width of the body limits the length of the shaft available for the engine and transmission gear, particularly in connection with multiple-cylinder engines. The crank shaft is usually provided at one end with ratchets for starting purposes, with a gear for driving the cam shaft and any other fittings such as pump or magneto, while at the other end the fly-wheel and the connections for the transmission gear are placed.

In some cases the fly-wheel is on the end of the crank shaft opposite the transmission gear, but this is not considered the best practice, because, in suddenly setting a clutch, the inertia of the fly-wheel is transmitted through the shaft to the transmission gear, causing a more or less severe strain on the shaft and requiring a stronger shaft than would otherwise be necessary. In two-cylinder engines it is customary to set the two cranks of the shaft opposite each other, or 180° apart. Other arrangements have been used but have not been found so satisfactory as this. In three-cylinder engines, the cranks are 120° apart and in four-cylinder engines they are 180° apart or the same as if two two-cylinder cranks had been joined end to end with the two outer pistons moving together and the two inner ones together. For six-cylinder engines the setting is the same as if two three-cylinders had been joined—the inner, intermediate and outer pistons respectively moving together. Three bearings for a four-throw shaft and four bearings for a six-throw is quite common practice, as is also five and seven bearings respectively. A few engines have cylinders which revolve around a stationary crank shaft, and in these a single throw shaft is usually used, the Adams - Farwell having five connecting rods attached to the single crank pin. When the engine "knocks" at speed, whether hot or cold, a loose connecting rod or loose fly-wheel should be looked for, lest the shaft be broken by the constantly repeated blows.

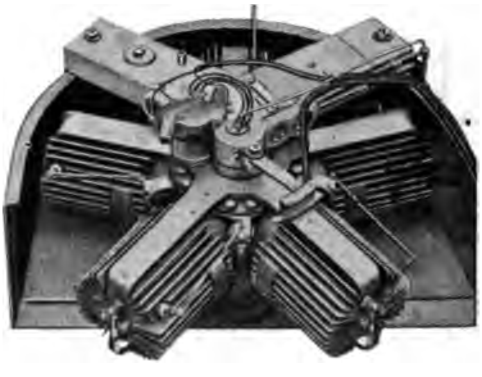


Fig. 13. Gasolene Engine with Revolving Cylinders.

Fly-Wheel. The fly-wheel of a gas engine is a sort of necessary evil. Since in a four-cycle engine there are three idle piston strokes to one working stroke, a fly-wheel is necessary to store up the energy of the one working stroke and carry the engine steadily through the three idle strokes. In a single-cylinder engine this fly-wheel must be of considerable size, weighing when used with a cylinder of 4½ x 4½ inch [illegible] 200 pounds. With two cylinders there are double the number of explosions and consequently only one idle stroke between the working strokes, so the fly-wheel can be reduced in weight nearly one half. With three cylinders the working strokes follow each other with but one sixth of a revolution intermission and a 55-pound fly-wheel, as used on the Duryea, after a long experience with a variety of weights, serves nicely. A three-cylinder engine may be run without any fly-wheel whatever, but this is not considered practical, although a 25-pound fly-wheel, 18 inches in diameter, serves quite well in a 12 H. P. engine, for all except very slow speeds, at which the separation of impulses becomes so pronounced that is is disagreeable.

In order that the weight may be as little as possible, the fly-wheel is made of the largest practicable diameter and the weight is kept as fully in the rim as may be. In many cases the interior surface of the fly-wheel rim is used to form the clutch surface, while the magneto pulley or pump pulley is driven by friction against the outer surface, which in some cases also serves as the driving face for a fan belt. The spokes are screw-propeller shaped in some instances, to throw air for cooling. In others the face of the wheel is a plane and is used for a friction disc, with the edge of another disc bearing against it, and shiftable to vary the speed of the driven disc.

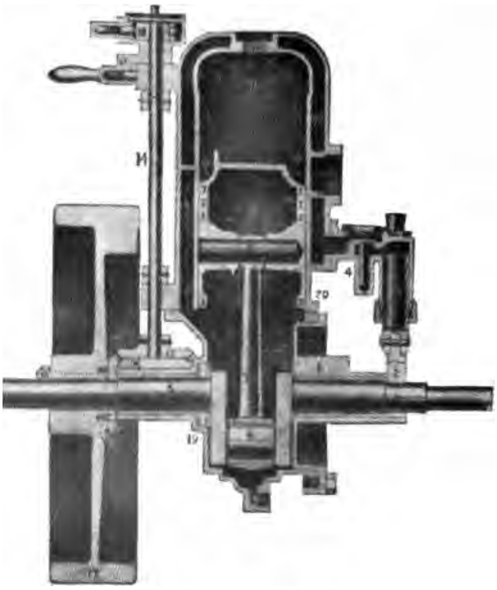


Fig. 14. Section of Gasolene Engine, Showing Enclosed Crank.

Crank Case. In a two-cycle engine the crank shaft is usually enclosed in a tight case arranged to hold pressure to the amount of 5 or 10 pounds under running conditions, although strong enough to hold an explosion which may sometimes occur in the crank case. The cylinder is provided with ports uncovered by the piston at one end of the stroke, which serve to exhaust the burnt charge and admit the new charge from the crank case into the cylinder proper. Most two-cycle engines are further provided with an inlet port uncovered at the opposite end of the stroke to admit a new charge from the vaporizer into the crank case, where it is compressed by the return, ready to pass into the working end of the cylinder on the opening of the transfer port. Some two-cycle engines have valves, usually of the poppet type, to pass the unburned gases, but these are generally automatic and do not add much complication.

In the four-cycle engine, the cylinders serve the double purpose of containing the working charge during one revolution of the shaft, and the new charge during the next revolution, thus avoiding the use of the crank case as a charge-containing chamber, but requiring two revolutions instead of one per explosion as in the two-cycle engine.

Valve Action. To accomplish this result with a single cylinder, valves are used both for inlet and exhaust, which are operated ordinarily by a half-time shaft fitted with cams arranged to open their respective valves during substantially one stroke of the four strokes forming the cycle. The exhaust valve is opened about 20 to 25 degrees ahead of the crank shaft dead center, and closed at the opposite dead center one stroke later. The inlet valve immediately opens, and it closes at the end of the next stroke one revolution after the exhaust valve opens. Both valves remain closed during the compression and working strokes.

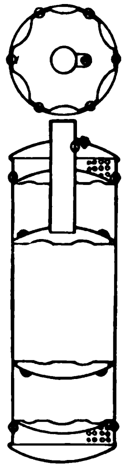


Fig. 15. Diagram of Valve Action.

These valves are variously placed according to the ideas of the designer. A common arrangement places them in the head of the engine with stems projecting from the crank shaft, in which position they are usually opened by rocker arms and plungers actuated by cams on the half-time shaft located in the crank case. In a great number of instances the cylinder or cylinder head is provided with a port passage or pocket on one side of the cylinder head and the exhaust valve is seated therein with its stem projecting toward the crank shaft. The inlet valve may be similarly seated in a similar pocket, or in the same pocket with the stem projecting in the opposite direction. An advantage of having the inlet valve in the same pocket is that the incoming charge cools the exhaust valve and also the sparking parts, which are frequently located in the same pocket entering through the side thereof, or as in the Duryea, through the exhaust valve stem. It is evident that one pocket requires less cylinder wall than two and therefore loses less heat to the cooling system.

The size of the valves depends much upon the speed required and should be quite large if a high speed is desired. Very satisfactory practical results are obtained by making the exhaust valve one third the piston diameter and the inlet valve one fourth, although to save variety of parts, some designers use the same size valves in both instances, but do not lift the inlet valve so high. Variable lift valves are much in favor because this prevents unnecessary valve movement with consequent wear and noise. In some cases this variable lift is secured by introducing a wedge between two parts of the lifting mechanism, and in other cases by holding the valve against more than a limited lift in response to the suction of the piston, as in the variable lift inlet valves of the Duryea.

Auxiliary Exhaust. In order to get rid of the excess heat, and relieve the regular exhaust valve of part of its duty, some engines are provided with an auxiliary exhaust, consisting of a port through the cylinder wall uncovered by the piston at the end of the working stroke, as in the Fredonia and Franklin machines. It is considered advisable to provide this port with a check valve to prevent back pressure from the muffler from re-entering and lessening or possibly igniting the new charge; although this is probably not so necessary in single or double cylinder engines. Many designers consider the auxiliary valve as an unnecessary complication, used only where the regular valve is inadequate.

Muffler. Connected with the exhaust opening by piping of convenient length, is the muffler, consisting usually of several chambers generally cylindrical, and having walls of sheet iron. This device has usually several times the capacity of the cylinders, which permits the exhaust gases to expand considerably and exposes them to the cool walls, thus reducing their volume by cooling, so that as they escape to the atmosphere they make much less noise than if permitted to escape without the intervention of the muffler. Multiple passages as well as multiple chambers are usually provided, and the silencing effect seems to be largely derived from interference of the sound waves and gaseous impulses.

Most mufflers offer some back pressure, but if of sufficient size, and provided with three to six chambers, the exhaust of the ordinary auto engine can be silenced as effectually as other noises about the vehicle, with so little back pressure as to not be perceptible in the propulsion of the vehicle if a cut-out is used. Mufflers sometimes clog with soot and dust and do not permit free escape of the gases, particularly at high speed. The large part of the burnt charge remains in the cylinder and prevents the entrance of a new charge, with consequent failure to produce power. Muffler explosions are due to missed fires in the cylinders, which allow the unburned charge to pass to the muffler, where it is ignited by the next exhaust and explodes quite noisily, and sometimes to the damage of the muffler. Muffler cut-outs are often used on hills or where great power is needed, and they avoid any back pressure from the muffler.

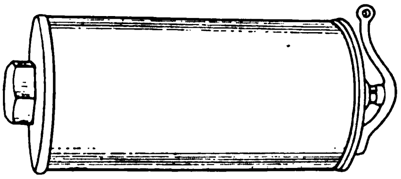


Fig. 16. Muffler and Cut-Out.

Vaporizers. Connected to the inlet ports is the device for mixing the liquid fuel, commonly gasolene, with the proper proportion of air to make an explosive mixture. Formerly this was done by a device for passing the air through the liquid contained in the tank, termed a carburettor, and while good results were obtained therefrom, it was more delicate and not so satisfactory to adjust for varying weather conditions as the devices now used. Present-day devices are modifications of the well-known atomizer used for perfume and medicine sprays, and might better be termed mixers or atomizers than carburettors. Since, however, the liquid after being sprayed, is intended to be vaporized before ignition, a common and correct term for this device is vaporizer. There are many modifications of this device but in general it consists of a small gasolene chamber in which the level of the liquid is controlled more or less perfectly, by a float, the chamber being vented so as to permit admission or abstraction of liquid without establishing a compression or vacuum.

From the float chamber a small passage, usually controlled by a needle valve, leads to the spraying tube, which is so placed that the air drawn in by the suction stroke of the engine must pass the point of the tube, and in passing, suck out and spray the gasolene in the required manner. In order to give the air greater speed and a more powerful effect, it is customary to make the air tube contracted at the point where it passes the spray tube, although very satisfactory vaporizers have been produced without this modification. Since at high speeds the liquid gasolene flows more than proportionately fast as compared with the air, it is quite common to provide a light valve, spring closed, to be opened by the increased suction as the speeds increase and to admit air in proper quantity to compensate for the increased amount of gasolene. This valve in some forms is actuated by a large dia-

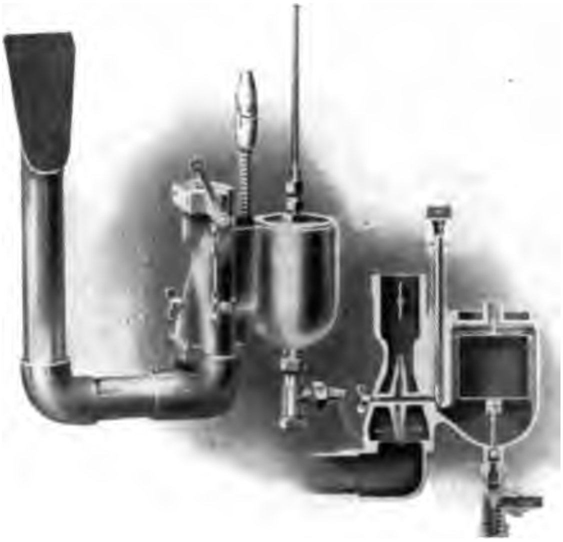


Fig. 17. Carburettor.

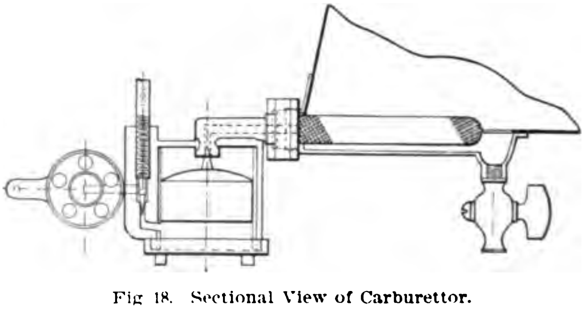


Fig 18. Sectional View of Carburettor.

phragm, as in the Krebs, and is sometimes provided with a dash-pot.

In some vaporizers the air and gasolene openings are varied by the throttle, which is also varied to control the speed of the engine, and since the screw threads, or devices controlling the variation, may be made as desired, a fairly constant quality of mixture may be secured from vaporizers of this type, subject, however, to the fault that if the throttle is open wide but the engine running slowly, the adjustment intended for high speed will be in operation at low speed, and thus is not so satisfactory as an automatic suction-operated arrangement. The early Kingston carburettor was of the throttle-controlled type. In still another type, of which the Duryea is an example, the air-flow passes through an opening fixed in size except for starting, but the gasolene-flow is varied by lowering the level in the float chamber at high speeds. This is accomplished by the use of a chamber slightly larger than the float, so that little or no reserve gasolene is carried, and this is drawn out immediately at high speed, causing the float to fall and open the passage into the float chamber. The float is provided with a long taper point which requires a considerable movement of the float, in obedience to the considerable variation of the gasolene level, in order to supply the amount of fuel needed at high speed.

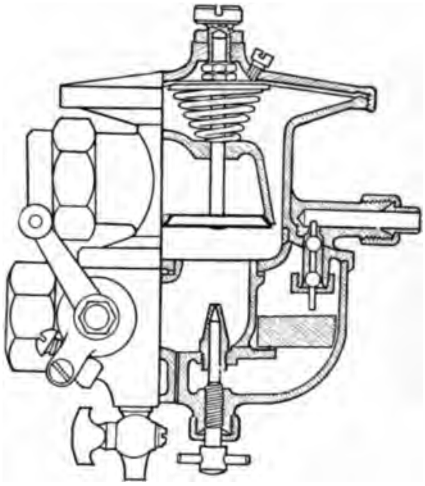


Fig. 19. Automatic Compensating Carburettor.

In still another form, invented by Dunlap, of pneumatic tire fame, the gasolene passage is impeded by a saw-toothed wire, against which teeth the gasolene, at speed, impinges with such violence as to obstruct its flow and lessen the amount passing from the spray tube. Still another form of mixing device does not use the float chamber, but admits the air and gasolene through proportionate valves closed by a spring and opened by the suction of the motor with consequent admission of proportionate amounts of liquid and air. The original Winton and the Lunkenheimer generator valves were of this kind.

Vaporization. The vaporization of a liquid requires heat, which, in the case of a gas engine vaporizer, is usually obtained from the air with the result that the temperature is decidedly lowered where the vaporization takes place, viz., between the spray tube and the engine, principally near the spray tube. If the atmosphere contains much moisture, this cooling effect causes a deposit on the walls of the vaporizer or its tubing, which is frequently frozen, forming slush or white frost, sometimes to such a degree as to actually close the passage and prevent further formation of proper mixture, with consequent stoppage of the engine. To prevent this and to insure a more homogeneous mixture, heat is usually supplied by drawing the air from near some heated portion such as the exhaust pipe or exterior walls of the cylinder, or by applying heat to the outside of the vaporizer or pipes by directing some of the exhaust gases against them, or by surrounding the parts with warm water from the water jacket. No method secures absolutely perfect results, for atmospheric conditions vary so widely from day to day that only constant readjustment can meet the varying conditions.

Vaporizer troubles are usually due to improper adjustment, the mixture being either too poor or too rich. If the engine will run, the adjustments can be varied and the result noted, while over-rich mixtures will be quite apparent by the odor of carbon monoxide in the exhaust. If the engine will not run, test the mixture in the cylinder by removing a spark plug or peep cap and applying a flame, being careful not to get fingers or face in front of the opening. If the mixture burns bluish with little violence, it is too poor, but if it burns yellow and slow, it is too rich. A proper mixture explodes with a violent outrush of gas.

Frost in the air tube will so obstruct the passage as to prevent the entrance of a new charge and produce loss of power much like a choked muffler. A little hot water will quickly warm the pipe. Water or ice in the gasolene will cause trouble unless removed. The water frequently manifests its presence on rough roads, and a drop of water in a passage which will not obstruct the flow—has, when frozen, completely shut off the gasolene. Dirt particles also must be guarded against.

Excess Cooling. Since the auto engine is a heat engine it is desirable that it be as hot as is permissible, in order that the heat may be utilized for work instead of passing into cold walls and being wasted. It is well known that a cold engine runs with little power until warmed up, and while part of this lack of power may be due to the stiffness of the lubricating oil,—since this is intended to resist a high heat and must be of high fire-test and of considerable body—much of the lack of power is due to the cooling effect of the cold walls, which absorb the heat from the burning explosive charge and reduce the pressure that, with hot walls, would be expended in doing active work against the piston. Tests have been made which show that a very perceptible increase of power results from the use of hot water for cooling instead of cold water, and stationary engineers who have permitted a flow of water through the water jacket so rapid as to keep the jacket and walls cool enough to not be uncomfortable to the hand, have found a very decided increase in power when the water was caused to flow more slowly and leave the jacket substantially at the boiling temperature.

It is now generally admitted that a temperature slightly below boiling is most satisfactory where water is used for cooling; for if the water does not boil, no steam is formed, and no parts in the water jacket are left without water, with possible danger of overheating. These facts, now well-known, prove the theory that a heat engine should be run hot in order to give most efficient results, and it is the aim of designers to so design their productions that no parts shall be over-hot but that all shall have as high a temperature as is permissible. The principal limitations are premature ignition and faulty lubrication.

Premature Ignition is objectionable because of the negative work done on the piston before it passes the dead center, which not only results in lost power, but usually in a decided knock or pound, annoying to the passengers and destructive to the bearings. Since a poor mixture ignites less easily than a rich one, premature ignition can be frequently lessened and sometimes avoided by varying the quality of the mixture—a proceeding which also adds to the economy. Since compression heats the explosive charge, nearly proportionate to the amount of the compression, an engine designed to run hot should have a large compression space with consequent low compression. The increased economy of the less rich mixture in conjunction with the

est quality, and that cheap and dirty oil sometimes sold as gas engine oil, is not suited for this work.

An oil suited to steam engines using superheated steam, will in almost all instances, give excellent satisfaction in auto engines. The makers of the vehicle will gladly advise what oil should be used in connection with their product, and when a good oil is once found, it is wisdom to continue its use. If an oil is too thin it does not protect the metal surfaces properly and does not make a good packing nor properly assist the rings in holding the pressure. If of too low fire-test, it boils away as a blue smoke or vapor and leaves the surfaces dry, frequently causing them to cut, and sometimes ruining the cylinder or stopping the motor. A sudden loss of power without apparent cause may, with good reason, be looked for in the cylinder, since lack of lubrication makes a great difference in the friction of the piston, even though the parts are not cutting or have not seized. An excessively thick oil with needlessly high fire-test has no disadvantage except that being stiffer when cold, the engine is more difficult to start. Such oils are decidedly more economical because they wear longer and need be fed less rapidly. Good auto oils usually have fire-tests ranging from 600 to 800 degrees.

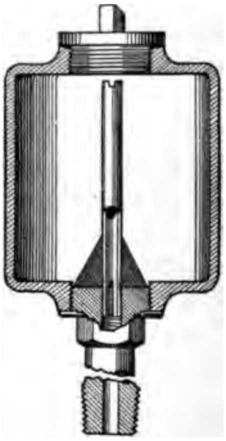


Fig. 20. Lubricator.

If for any reason, proper oil cannot be had, an oil of lower fire-test can frequently be used, but it must be fed in larger quantity and more carefully watched to make sure that it is serving its purpose.

Water Cooling. Consideration of the above facts will show the importance of proper cooling, and something of the loss due to excessive cooling. In a water-cooled engine, the water being unconfined, cannot become hotter than 212° and may, with little trouble, be kept nearly at this point, which is admitted to be most satisfactory, so far as present experience goes. Further, since water in boiling absorbs a great volume of heat, commonly termed latent heat, in its conversion into steam, it is especially adapted to the work of cooling. An increase of work on the part of the engine, with consequent increased development of heat, simply increases the rate of boiling without increasing the temperature appreciably, and thus avoids warping the cylinder wall or vaporization of the lubricating oil.

A most efficient cooling system consists of a tank or reservoir of water above the engine, piped to enter the water jacket on the underside and to return from the water jacket to the tank on the upper side of the engine, which return carries off any steam that may be formed in the water jacket, which steam being lighter than the water, causes the water with which it is mixed to move rapidly upward out of the water jacket and to be replaced by cooler water from the tank. This method of circulation is known as the natural or thermo-syphon method, and is preferred by many designers because of its simplicity. When it is not convenient to use natural circulation, a pump, driven by the engine, is introduced in the circuit and forces the water rapidly enough to nearly or quite prevent boiling under extreme conditions. A forced circulation, however, is not so good as the natural because it is not self-regulating, and therefore if it is fast enough to meet the needs of the engine under extreme conditions, it is usually too fast under ordinary conditions, and results in keeping the temperature of the water in the water jacket much below the boiling point and therefore below the point of greatest efficiency.

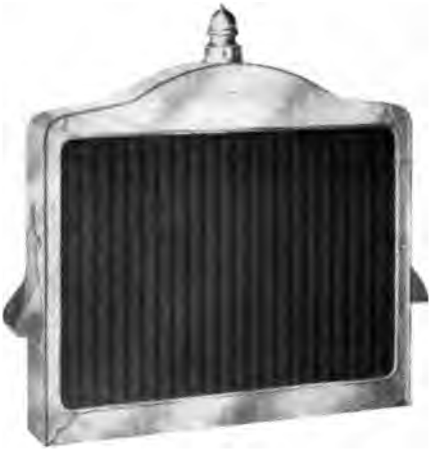


Fig. 21. Radiator.

To overcome this objection, some designers employ natural circulation between the engine and the small tank located near and above it, and employ a pump with radiator for the purpose of preventing the water in the tank from getting too hot to condense the steam that may pass into it from the engine. This arrangement gives the benefit of both systems with but little, if any, increased complication.

Since an auto engine of large power develops much heat, a goodly quantity of which passes away through the cooling system, it is quite evident that the water in the tank will soon become boiling hot unless provision is made for cooling it by the air through which the vehicle passes. It was formerly quite common to provide the tank with air tubes, thus greatly increasing the amount of surface exposed to the air and permitting a more rapid escape of the heat. Other designers employ pipes either plain or with radiating fins, so as to still more largely increase the radiating surface exposed to the air. Still others make their water tanks almost wholly of air tubes, with very small water spaces between, thus getting into a small radiator a great many square feet of cooling surface. In this form of radiator it was found that the natural circulation of the air is very slight because of the small size of the passages, so fans driven by the motor are most frequently used to either draw or force the air through these radiators at a rapid rate and with great cooling effect.

A further advantage of the air-fan in connection with the radiator is that the cooling is not dependent upon the speed of the vehicle nor the force of the wind but is varied by the speed of the motor, and therefore more nearly meets the needs of the motor than any other system excepting the natural system, first mentioned. If for example, as in hill climbing, the motor is running slowly, but with full charges, much heat is developed, but the fan also moves slowly, with very little cooling effect, whereas in the natural system, until the water begins to boil, the circulation is very slow and the more rapid the boiling, the more rapid the circulation becomes. This results in a truly thermostatic circulation, regardless of motor or vehicle speeds, due to the difference in density of the cool water in the radiator and the hot water containing more or less steam in the jacket which is sufficient to meet the requirements of some engine designs. In others, a pump to circulate the water is used.

There have been employed steam condensers in connection with the water jacket by which arrangement no water tank nor pump is needed, because the slight amount of water in the jacket when turned to steam, is condensed by the condenser and at once returned to the jacket. Practically all water-cooled engines form steam at some time, which, not being provided with suitable condensing surface, escapes from the system, thus requiring occasional addition of water. It is considered advisable to have a tank of water above the cylinder jacket, so that the cold water may condense this steam and also keep the cylinder filled. This tank carries from two to ten

Most radiators are tubular and on the tubes are fitted and soldered disks of metal, which serve to conduct the heat from the water out to the air, which, by the passage of the vehicle, is thrown against the metal surfaces. These flanges are formed in some instances by crimping a strip of metal along one edge and winding it spirally around the tube, the crimped edge being soldered to the tube. This avoids waste of metal and makes a very efficient radiator. The height of the disk edges above the tube is usually ¼ to ½ an inch or about 10 to 20 times the thickness of the metal, the smaller sizes being most efficient.

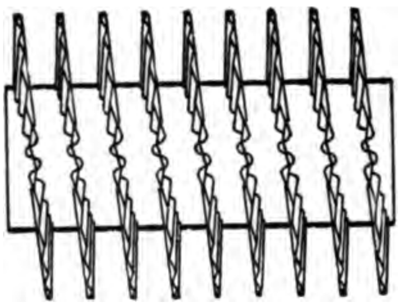


Fig. 22. Radiator with Spiral Flanges.

In some cases the water tank is cooled by tubes passing through it, which permit a flow of air. These tanks vary from those of large water capacity, having a half dozen or more one-inch tubes, to tanks of small contents completely filled with tubes, either square or round, ½ inch in diameter or less, by 3 or 4 inches long. Such a device is called a cellular or honeycomb radiator, because the tubes suggest the cells of a honeycomb. This type of radiator contains a very large cooling surface, divides the water into thin sheets and is quite efficient, but it is expensive to make, has many joints likely to leak, and the fine passages are easily clogged, on which accounts, the tubular form is now generally preferred. The tubes may be continuous, causing the water to travel the whole length, but later forms use a number of tubes connected at their ends by heads or top and bottom tanks, and the water flowing from one end to the other, is divided, so that a small portion only flows at slow speed through each tube. This arrangement relieves the pump of much of its duty.

Air Cooling. Since in any event the heat is dissipated into the air, it is argued by many that air cooling is the most logical form, and many attempts have been made to produce successful air cooled motors. The total heat in the burning charge varies as the cube of the cylinder dimensions, whereas the wall surface varies only as the square; so it has been assumed by many that large engines are of necessity more difficult to cool than small ones, and that air cooling, while applicable to small powers, is not suitable for larger ones. Others maintain, while admitting the above statement as to the total amount of heat, that the heat received by the wall from the gases in the engine must come from the gases adjacent thereto, and that on this account the wall will be little, if any, hotter in the one case, than in the other, and that large auto engines can be cooled just as readily and practically as small ones.

Since, however, the size of engines used in auto work is limited by the weight of the parts and the intensity of the vibrations set up by the explosive charge, it seems quite likely that the latter contention is practically true. It is now no longer common to increase power by increasing the bore of the cylinders, but the accepted method is to increase the number of cylinders, and it was quite thoroughly demonstrated by Knox and others, that cylinders up to 5 inches bore, of varying strokes, can be successfully air cooled.

The most common forms of air-cooled cylinders are either cast with flanges encircling them or machined out of a solid body of stock or forced on by pressure after the cylinder is machined. Other forms have the cooling flanges cast lengthwise of the cylinder. If the engine is horizontal the encircling flange permits the hot air to pass freely away, which is not the case when the engine is placed vertically, unless a fan or some means for moving the air horizontally is provided. For vertical engines using natural air circulation, the lengthwise flanges are undoubtedly best.

Many air-cooled engines are fitted with special forms of cooling surfaces such as threaded pins having one end screwed into the cylinder wall, which pins not only carry the heat outward, but because of the screw threads on their surfaces, are in contact with a large volume of air. Grooves are frequently machined into the cylinder surface, in which are chalked combs or strips of radiating metal having large radiating surface.

In all the larger motors, fans are used to direct a current of air past the radiating surfaces to insure effective cooling.

In some engines, as in the Frayer-Miller, the cylinder is enclosed in a jacket, through which air is forced and by which the air is caused to come in close co [illegible] heated surface with the result that the cooling is pos [illegible] e effective where needed, and is largely proportioned to the needs of the engine, because the blower which supplies the air is driven by the engine. In air cooling, however, unlike water cooling, there is no fixed temperature point and there is, therefore, much more variation in the walls of the cylinder, with consequent possible warping, than is found in a water-cooled motor. This variation is believed by many to shorten the life of the engine and increase its troubles, while others argue that the avoidance of the water system more than makes up for the lack in this respect.

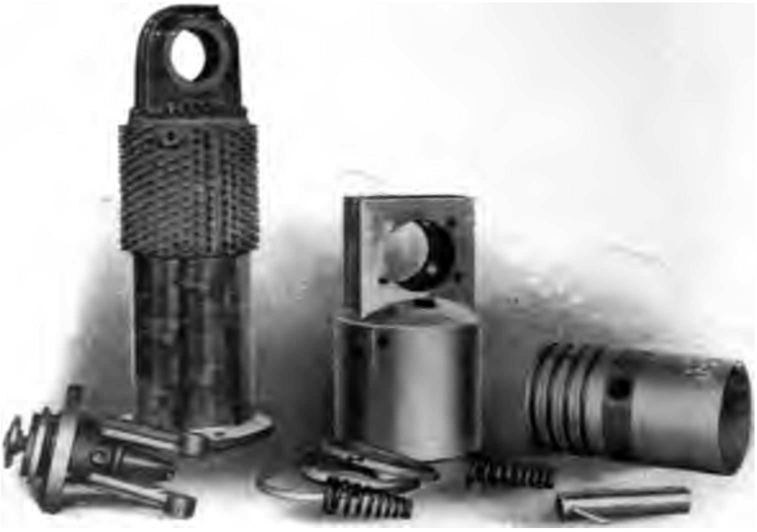
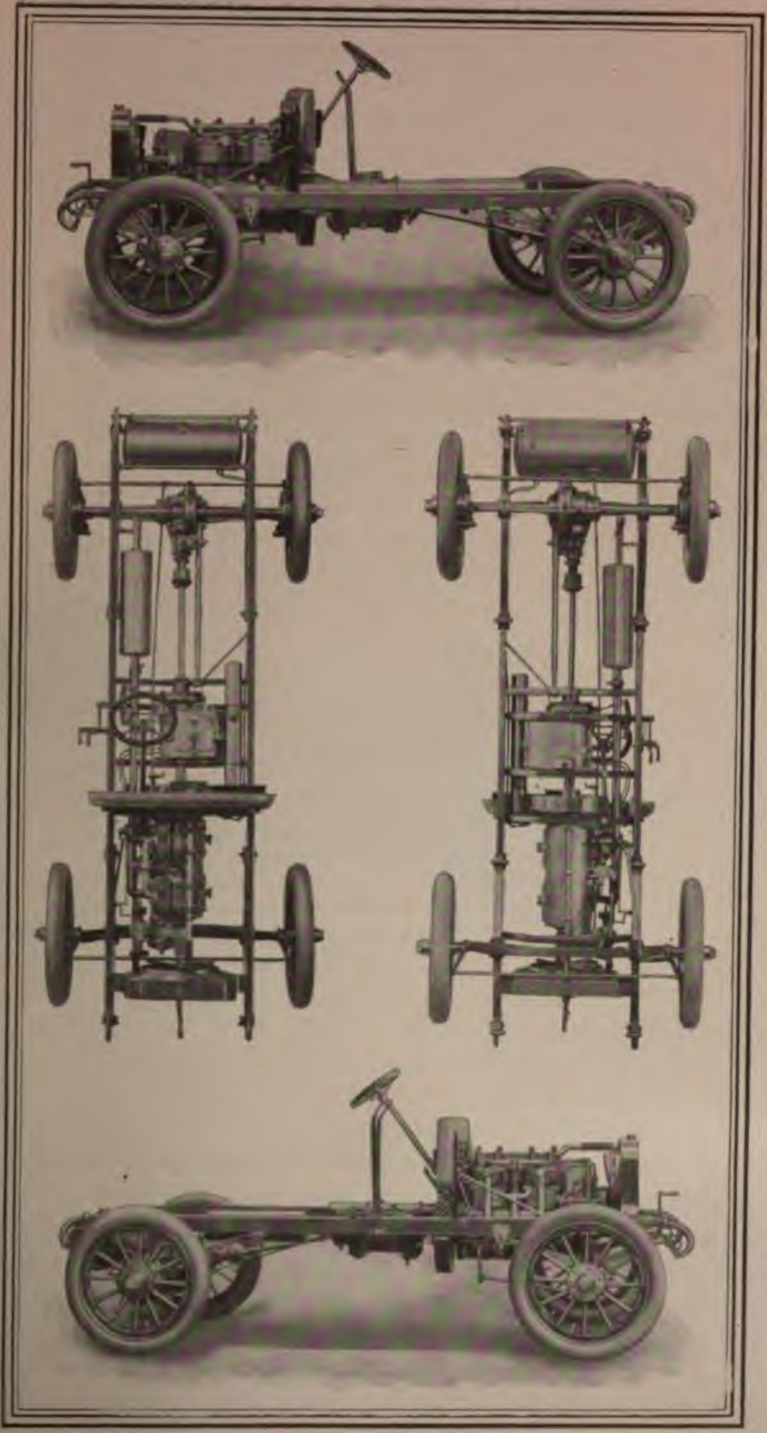


Fig. 29. Frayer Miller Engine Parts.

The aluminum jacket slips down over the cylinder head, the valves being put in from opposite sides. Air is forced down from the top of the jacket passing equally to all sides, cooling the cylinder without warping.

CHANGE-SPEED DEVICES

Second in importance only to the motor is the mechanism for conveying its power to the rear axle, or to the propelling wheels. This mechanism consists usually of first, a change-speed device by which the ratio of motor revolutions to rear-wheel revolutions is varied to meet the varying road conditions, such as hills, mud, sand, snow, crowded traffic or clear level roads; second, of a transmitting device such as a shaft, chain, or chains, or belts between the change-speed gear and the rear wheels; and third, of a balance gear often called a



GROUP OF MODEL K CHASSIS
The Winton Motor Carriage Co.

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differential, or its equivalent, by which the power is divided and caused to drive both wheels, while permitting freedom for the purpose of turning corners.

Change-speed gears are of many varieties, of which the most common are planetary, sliding gear, individual clutch, friction, automatic and several others, combining more or less of the various features found in these forms with possibly slight variations, such as magnetic, pneumatic or hydraulic clutches. Few subjects offer a greater field for ingenuity than change-speed devices, and many forms not worthy of description in the limited space available, have been tried and found reasonably satisfactory.

Planetary Gear. The planetary gear was the first form to be largely used in America, being first regularly employed on Duryea vehicles in 1898 and afterward adopted in the Olds runabout and by its many imitators, as well as in the Cadillac and Ford machines, in all of which it is still found, as well as in many others. In its original form it employed a spur driving gear attached to the crank shaft. Meshing into this was a planetary pinion carried by a stud projecting from a frame journaled on the crank shaft end, which frame carried the driving sprocket. Meshing into the pinion, was an internal gear concentric with the crank shaft, and the device was provided with three clutches, one for locking the parts together, so that all would revolve with the crank shaft, forming direct drive on the high gear; another for holding the internal gear stationary while the pinion rolls around inside it, carrying the sprocket forward at low speed; and a third for holding the pinion frame and causing the sprocket to be carried by the internal gear in a reverse direction as the pinion revolves. (The sprocket having been first released from the pinion frame.)

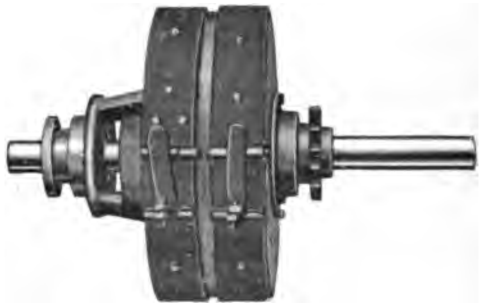


Fig. 24. General View of Planetary Gear.

These clutches were operated separately, only one, as a rule, being engaged at a time. A single operating lever was usually employed for high and low speed, while a second lever was used for the reverse. Two to four pinions were employed instead of one, which gave added strength without requiring additional room, and thus permitted the gears to be of much narrower face for a given duty than would have been possible with a single form. Modifications of this device employing two or more sets of gears are largely used because the original form was protected by patent, but the principle is much the same in all. The diagram herewith illustrates the action more fully. As usually constructed, the planetary system provides two speeds forward and a reverse, but some forms provide for three speeds forward together with a reverse.

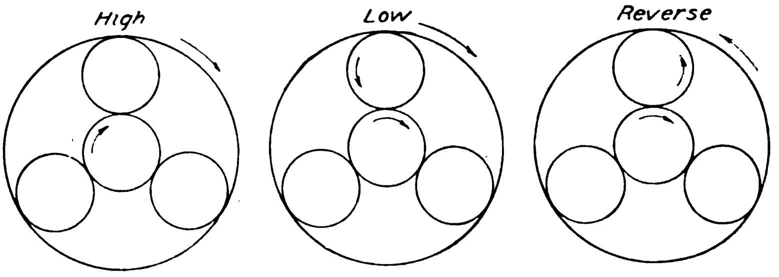


Fig. 25. Planetary Gear Diagram.

All parts locked together, gives high gear and carries the sprocket at same speed as crank shaft without friction or moving parts.

Holding the large internal gear causes the intermediates to roll forward slowly and carry the sprocket with them, giving low gear, one-third to one-fourth the crank shaft speed.

Holding the spindles of the intermediates drives the internal gear in a reverse direction, giving the reverse speed.

Individual Clutch. The individual clutch transmission is still an older form, having been used by Duryea in '93, Haynes in '95 and by several foreign makers fully as early. This consisted usually of two parallel shafts on which were two or more sets of spur gears of different sizes but of a common distance between centers. Each set of gears was provided with a clutch adapted to cause that set of gears to transmit power at its proportionate speed when desired by the operator. For reversing purposes, sprockets and chain instead of gears were used, or one set of gears small enough not to mesh, but provided with an intermediate, were employed. The individual clutch system permits a wide variety of speeds, smooth and noiseless engagement of any speed, and is a very satisfactory system, its principal objection being the large number of clutches and the fact that all sets of gears are in motion at all speeds. To avoid clutches some designs employ a single friction clutch and a movable key or pawl by which any gear can be locked to the shaft, and speed changes are made by sliding this key from one set of gears to the next. The strain on the small key results in its rapid destruction and forms the principal objection to this arrangement. Similar results are obtained by sliding the gears themselves, which although not so compact, is considered a stronger and more desirable device.

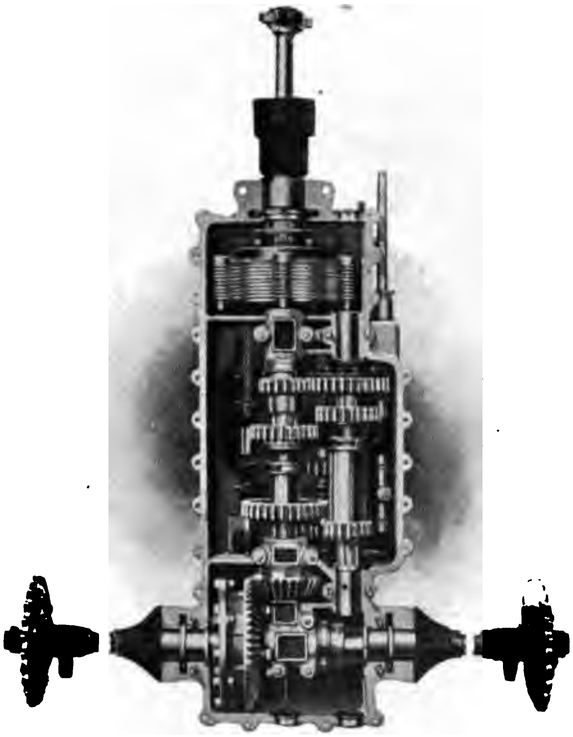


Fig. 28. Clutch, Sliding Gear and Counter Shaft.

Sliding Gear. Possibly the most used form to-day is the sliding gear. This, like the other forms, is made in a number of varieties but, in general, consists of parallel shafts, and multiple sets of gears of differing proportions. On one shaft the gears are fixed, while on the other they are commonly attached to a sliding sleeve, which is either fitted to a square shaft or provided with a spline and key-way to prevent rotation of the gears without rotating the shaft, and yet permit free movement of the gears along the shaft. The gears are placed at such intervals that when one is engaged, the others are disengaged. In operation, a single clutch, generally located in the fly-wheel, is withdrawn while the gears are being shifted, after which the clutch is allowed to engage and propel the vehicle. The ends of the gear teeth are sharpened so that they will engage each other easily and thus permit shifting from one set to another without difficulty. If the clutch is not fully withdrawn, the ends of the teeth about to engage, strike against each other, often making considerable noise and sometimes breaking the teeth.

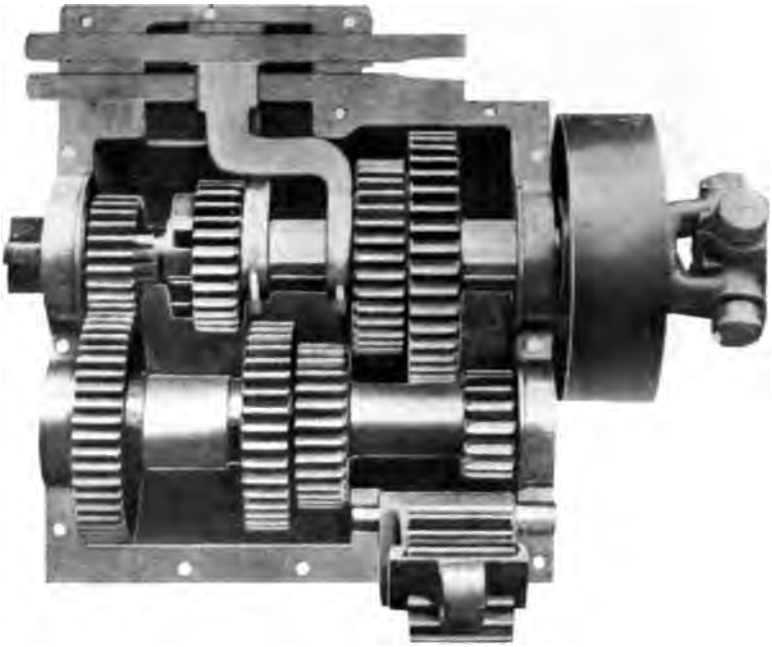


Fig. 27. Sliding Gear Set.

In the better forms of sliding gear designs, the main shaft is divided in a gear box, and the power transmitted to the second shaft is, by an additional set of gears, returned to the second part of the main shaft and by it transmitted to the wheels. At one speed, usually the highest one, the two parts of the main shaft are connected by a clutch of the positive or jaw-clutch variety, while the parallel shaft with its gears is completely disengaged and stands idle. This gives a direct drive, free from needless friction and is considered quite advantageous. In some forms, two of the sliding gears are on one side and two on the other. This, of course, requires two shifting forks in its operation. Other forms employ a shifting fork for each gear and a selective means of engagement by which the operator can cause the single shifting lever to engage any desired fork, and thus put into operation any gear which is brought out of operation as the lever passes to neutral, where it is again ready to engage any desired gear.

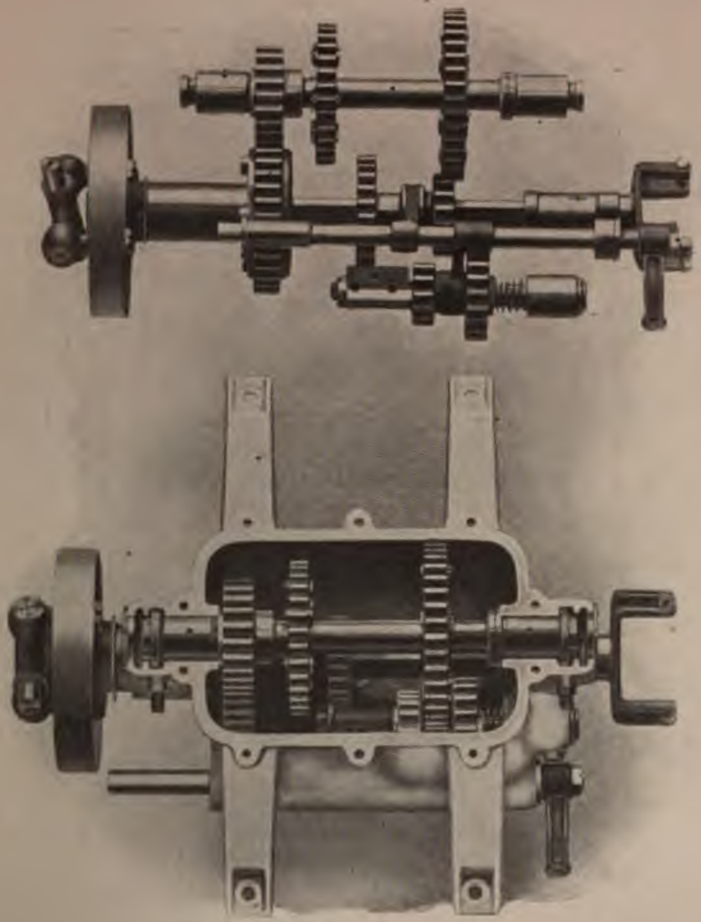


Fig. 28. Sliding Gear Transmission.

The objections made to the sliding gear device is that this method of meshing gears is unmechanical, wears the gears rapidly, is likely to break them, and the means of shifting is much slower and therefore less safe and handy than the individual clutch or the planetary systems. It is argued, for example, that in the sliding gear the operator must withdraw the clutch, then withdraw the gear, then shift the gear lever, then cause it to engage a different gear and finally complete the operation by letting in the clutch–a total of five movements. In the planetary device the same motion that withdraws the high clutch will, if continued beyond the neutral point, engage the low one and vice versa, while in the individual clutch system one movement disengages the clutch and another, usually of the same lever, engages another clutch, with its corresponding gears; at most two movements, and in many forms accomplished by a single movement.

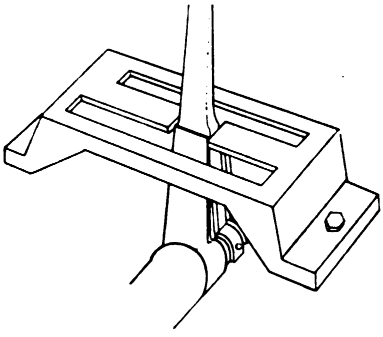


Fig. 29. Single Lever Quadrant, Selective Type.

The importance of quick action in a crowded street or on a steep hill can hardly be overestimated, particularly since motor vehicles are rapidly-moving devices and but little time can be allowed for the performance of any simple function like speed changing. In spite of this disadvantage, however, the sliding gear seems to be increasing in popularity, which is probably due to the fact that many people regard the foreign vehicles as superior to the American, and the sliding gear is a foreign device. It seems also probable that the greater simplicity of the sliding gear system as compared with the individual clutch has caused it to find favor with the makers, to whom simplicity means cheapness, and who are not so much concerned as to whether or not it is most easy to operate. The simple device is not only cheapest for the manufacturer but it is generally more easily understood and maintained by the owner, and should, if other things are reasonably near equal, be given preference.

Friction Gear. The friction gear, although but little used, is an exceedingly old form. It was probably the first form in the thought of every designer in connection with the gas engine, for in the early days gas engines were regarded as being inflexible, and a flexible driving gear was considered an absolute necessity. Lack of positiveness, the objectionable pressure necessary to secure driving friction, the disturbing effect of grease, frost or water when found upon the friction surfaces, the large size of the discs required, and the constant loss of power due to the fact that variable friction devices cannot be constructed upon rolling cone lines, all conspire to make friction devices objects of suspicion to which most designers were unwilling to confine their efforts. Successful use for many years upon vehicles of even the heaviest weights has proved that friction driving gears are capable of successful use and excellent service, and that their advantages and objections compare favorably with other systems.

Several forms have been used, of which the most common form, and the one longest in use, consists of a disc on the engine shaft parallel to the plane of the fly-wheel and often formed by the fly-wheel itself. Parallel to this disc is a driven shaft on which the driven disc is arranged to slide with its edge in contact with the face of the driving disc. This driven disc can be shifted from the extreme outer edge of the driving disc, which is usually high speed position, to a position which is beyond the center of the driving disc, which is a reverse position. At the center the driving effect is nothing and the driven disc would stand still but is usually disengaged at this point. This form has been in use for five years on Union vehicles and has been thoroughly tested under every condition of road service.

A modification employs two additional discs, one journaled on the cross shaft with its edge engaging the reverse surface of the driving disc, the other journaled independently on a short shaft in line with the driving shaft and with its outer surface engaging the edge of its mate, while the driven disc engages its face opposite the point of engagement on the driving disc. This arrangement applies power to the driven disc at opposite sides, which balances the pressure and increases the driving effect to a considerable extent.

A modification of these forms reverses the positions of the discs and employs the shifting disc as the driving device with its edge moving across the surface of the driven disc. This reversal secures great power at low speeds, but for pleasure motor vehicles this is not so desirable, for they are usually driven on the high gear, depending upon the throttling of the engine for necessary variations in speed, and friction discs of this arrangement are quite wasteful of power when the transmission point is near the center of the disc surface. This is because of the fact that the point of contact is not actually a point, but covers a considerable surface, on which account a considerable slip and loss of power results. This slip is dependent both upon the width of the friction edge in contact with the disc and upon the curvature of that circle of the disc in contact at any particular time.

If we assume the contact surface to be more or less elliptical in shape, it will be seen from the diagram that the surfaces must slip in opposite directions on opposite sides of the center of the contact area, and that this slipping is both across and with the edge of the driven disc.

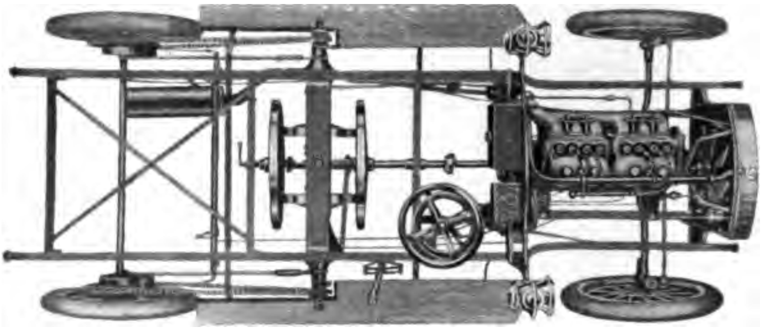


Fig. 30. Windsor Friction Drive.

A third form of friction in use on the Windsor vehicle is a modification of the second form. In this the driving shaft is equipped with two discs between which is placed two halves of a cross-shaft, each equipped with two edge-driven discs. These half shafts are so mounted that their adjacent ends can be thrown in opposite directions and the discs on them are likewise mounted to move oppositely and in like proportion. Since the driven discs are on opposite ends of the driving shaft, it is obvious that if one is thrown forward and the other backward, both will be rotated in the same direction, whereas if they are thrown in the opposite direction a reverse motion will be given. This obviates passing the center of the driving disc to secure a reverse, and since it is seldom or never necessary to have an extremely slow speed, the driven discs need not be shifted greatly to produce the variations in speed, which is done by shifting them toward or from the other edges of the driving discs. The illustration makes the arrangement plain without further explanation. The amount of clearance is so slight that the movement of the half shafts out of a direct line is too little to have any practical effect of a detrimental character.

A fourth form is arranged to make use of the friction drive only for such variations in speed as are necessary below direct drive, and secures the advantage of direct drive without loss for high speed work. This arrangement seems particularly adapted to pleasure vehicle service and will doubtless find large adoption in future. In this construction the driven disc stands parallel to the fly-wheel and is shiftable toward and from the fly-wheel surface. The edge of the driven disc engages the plain surfaces of two or more intermediate discs, journaled on short shafts parallel to the plane of the fly-wheel. The edges of these intermediates engage the fly-wheel by gear or friction as may be,

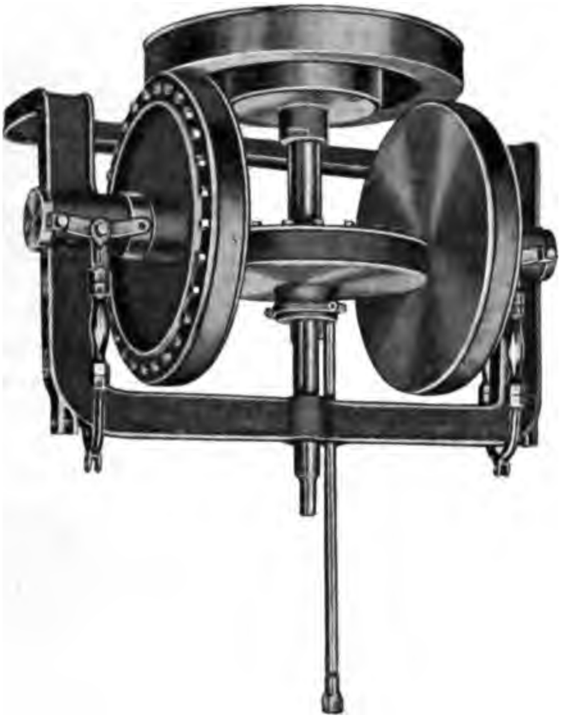


Fig. 31. Friction Drive for Variations in Speed below Direct Drive.

and transmit power to opposite sides of the driven disc. Shifting from the center of the intermediates toward the fly-wheel increases the speed, while in the opposite direction beyond the center gives the reverse. When near the fly-wheel a clutch is engaged, which connects the fly-wheel and driven disc positively after which the intermediates are disengaged, leaving direct drive on the high gear.

VEHICLE CONTROL

With all these devices the operator is called upon to perform certain operations, such as setting and releasing clutches, shifting the discs in and out of contact, or shifting and selecting the gears to be used. In the operation of the vehicle, he must have in mind the important function of speed changing, in addition to the equally important ones of steering and throttling the motor, together with minor functions such as spark management, lubricator oversight, and tooting the horn or sounding a gong, which is frequently required by law. Such a multiplicity of duties is confusing to many operators accustomed only to drive a gentle horse, which requires but guiding and speed regulation, and there is no doubt but that many accidents are due to the operator in an emergency becoming confused and failing to do the right thing to prevent trouble.

It is, therefore, quite necessary that vehicle control should be as simple as possible, and while some designers have eliminated minor details, such as spark control, and the necessity for watching the oil or water circulation, and have reduced the operation of the vehicle to steering and throttling, with sufficient power to drive a large and flexible engine almost wholly on the high gear, and without speed changing, others have eliminated speed changing entirely by making it automatic. Thus in the Sturtevant machines, the fly-wheel is provided with two or more sets of governor weights. When the engine is throttled extremely low, these weights are all drawn in by springs and all drives are disconnected, leaving the vehicle standing still. If the motor is speeded up, the lightest set of springs permit one set of weights to throw into engagement the low speed gears, and these continue in engagement until the vehicle attains considerable speed, when a second set of weights throw out, bringing into action a higher gear, which drives the vehicle at a higher speed. The lower speed gears become inoperative because of a ratchet provision which permits over-running the low gears, whenever the driven part acquires a speed above that imparted by the low gears. If the speed decreases, the high speed weights are drawn in by their springs and the low gears take up the work, until, as when stopping, they too become inactive because of lack of speed. This arrangement eliminates speed changing entirely and renders the vehicle more suited to the use of every member of the family than are most vehicles—a condition that sooner or later must come to pass.

Combination. In a few vehicles the motor has been used direct connected to a dynamo to generate electricity, which, either through a storage battery, or direct to a motor, is used to produce the necessary speeds. This system has not been largely applied to pleasure vehicles, but has seemed best adapted to commercial vehicles where, because of widely varying loads, widely varying powers are needed, and the electric motor not only provides a steady application of power, but in connection with the storage battery, is capable of great exertion for short spaces of time, and undoubtedly does give an almost ideal method of speed changing. The added cost and weight of a double system of this kind is quite likely the chief argument against it.

It has also been proposed to use pumps for water or oil directly attached to the engine, while a motor adapted to be driven by liquid was directly connected to the rear axle. Such a device, while doubtless flexible and smooth running, is admittedly inefficient and not easily maintained in proper working condition.

CLUTCHES

Since the gas engine must be started from an outside source, and runs with but little power when cold, it is practically necessary to have a clutch by which the engine can be disconnected from the driving gear or at least from the propelling wheels. The forms of these clutches are quite varied. In connection with the sliding-gear change-speed device the clutch is usually placed between the fly-wheel and the change-gear box and is generally of the conical variety, one member forming part of the fly-wheel and the other being attached to the shaft entering the gear box. One surface is usually faced with leather or similar material having a high friction coefficient, and a strong spring is arranged to hold the members in engagement. A pedal like a brake pedal is usually provided to withdraw the driven member, with a ratchet for holding it withdrawn while the motor is being started.

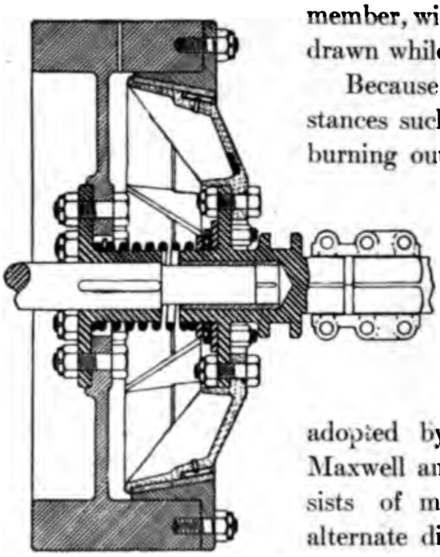


Fig. 32. Conical Clutch.

Because of the rapid wear of soft substances such as leather, and the danger of burning out the clutch surface in a few minutes after a clutch begins to slip, as well as because of the objectionable size necessary to secure an effective clutch of this kind, a better form of clutch has been recently adopted by leading makers, such as the Maxwell and Stevens-Duryea. This consists of multiple discs of metal, each alternate disc being attached at its edge to the driving member and the other discs attached at their centers to the driven member or vice versa. Light springs cause these to separate sufficiently to be clear of engagement when the clutch is released. The total amount of surface is so large that the friction coefficient may be very small. This form of clutch generally runs in oil, has no appreciable wear, needs no adjustment and the very worst that can happen is to burn out the oil between the discs and thus greatly increase their friction coefficients.

A very common form of clutch consists simply of a band, frequently lined with leather, vulcanized fiber, or even canvas, which is provided with means for causing it to grip the surface to be held. This form is commonly used in connection with planetary gears and is much employed as a brake device.

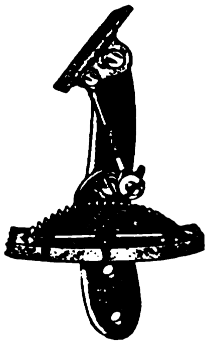


Fig. 33. Pedal and Ratchet.

In another form of clutch the surface to be gripped is not on the outside, as with the band, but is an inner circumferential surface, and two or more shoes or short segmental sections are caused to press against this inner surface by toggles operated by a collar shifted lengthwise the shaft. This is one of the earliest forms of individual clutches, and was used by Fawcett in an omnibus driven by an internal combustion engine at Pittsburg in 1876. A great variety of modifications of the devices just described are to be seen in use to-day, but with a knowledge of these most important forms the modifications are easily understood upon inspection. Square-jaw or positive clutches are used in some instances, as in the White steamer or the Chicago friction drive, and serve to change the speeds. Such clutches are used in some change gears instead of sliding the gears.

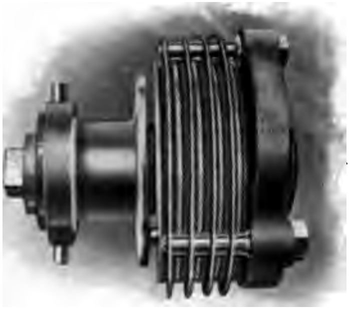


Fig. 34. Multiple Disc Clutch.

TRANSMISSION

After passing the change-speed gear, the power is transmitted usually to the balance gear, and for this purpose the single chain is the most common form. This is so simple as to need but little description, being known in its simplest and most successful form on practically all bicycles. The front or driving sprocket is usually small, the larger or driven sprocket being several (three or four) times the diameter of the front.

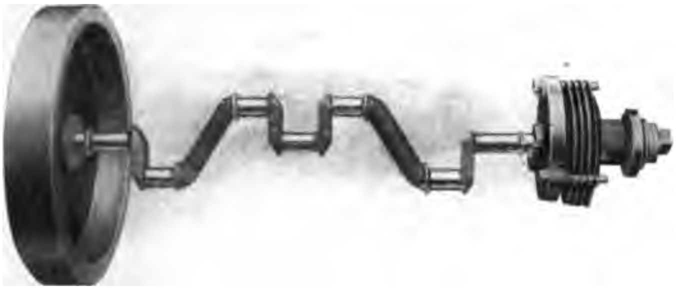


Fig. 35. Stevens-Duryea Fly Wheel, Crank Shaft and Disc Clutch.

The block chain adopted from bicycle service was the first form used on American motor vehicles, but being of bicycle size in almost every instance, was found totally inadequate and was therefore almost universally condemned. Not only the chain but the sprockets were too small, with the result that both wore out quickly and breakages were frequent. The block chain has less parts than the roller, has less joints to gather grit, is less noisy and, if of proper strength and properly fitted to the sprocket, runs with as little friction and transmits power with as great efficiency as any device yet offered. Few block chains are in use to-day, but of the few, the Duryea is noticeable because the blocks are bored transversely, so as to just intersect the rivet holes, and this transverse bore is filled with a felt pad, which absorbs oil and keeps the rivets properly lubricated. The value of oil upon any bearing is self-evident, and this arrangement not only insures oil in the proper place, but permits the outer surfaces of the chain being kept clean and practically free from grit, so that the rivets are not likely to wear in their bearings, nor do the teeth of the sprockets wear so rapidly as usual.

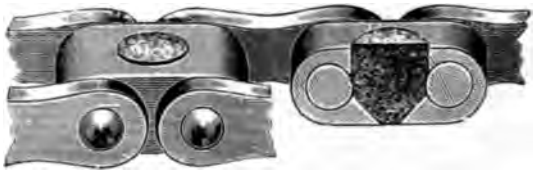


Fig. 36. Duryea Chain with Felt Lubricator.

The roller chain is the most common form and is so called because each rivet passes through a bushing around which bushing a roller is placed, so that the chain pull is taken by the roller bearing against the bushing, while the rivet is journaled inside the bushing. The reason for this is that as the chain lies down in its place upon the face of the wheel, the roller rolls down the teeth instead of sliding, but this reason is based upon chain imperfections and is not a proper one in connection with good chains and properly cut sprockets. If the chain and sprocket fit

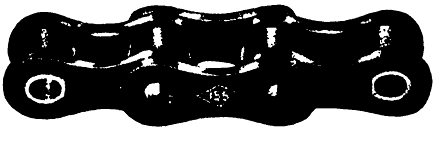


Fig. 37. Roller Chain.

properly, the pitch of the chain is slightly less than that of the sprocket, so that the rollers or blocks rise and fall out of and into their places, as the sprocket revolves, without friction. If, however, the chain is over-pitch, it will be loose at the middle of its length of contact on the sprocket and will grind and bind where it comes in contact and where it leaves the sprocket, and while rollers may partly overcome this grinding, the loss of power in any event, is decidedly objectionable, and such chains should not be continued in use.

It is to overcome this defect in driving chains that self-adjusting chains, like the Renold silent and the Morse silent chain, have been put upon the market. These have not come largely into use on autos because of their high first cost, but they are undoubtedly most meritorious, as they wear as long as gears, are more flexible, are less noisy, transmit as much power for a given width of tooth and need no more attention than gears. Their decided advantage is in the shape of the link, which causes the chain to select its own pitch line on the sprocket. Because of this feature they do not stretch and get out of pitch as do chains of ordinary construction, but any stretch of the chain, due to the wearing of the pivots, is compensated for by the fact that the chain automatically takes a larger pitch line position on the sprocket, whereas in chains of the usual kind an increase of pitch causes the chain to grind and rapidly wear the tooth surfaces, as the chain takes its position on the sprocket with much loss of power and with an increasingly rapid destruction of both sprocket teeth and chain.

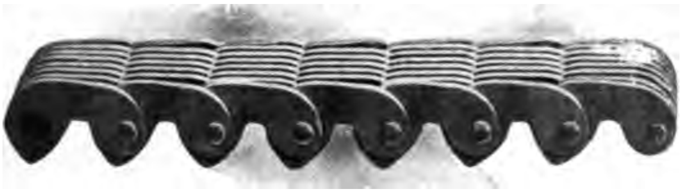


Fig. 38. Morse Silent Chain.

The pitch of a chain is the distance from center to center of similar rivets, having one chain link between them. In roller and the silent chains mentioned, it is the distance between rivets. In block chains each link is composed of one block and two side pieces, which are held together by a rivet, so that the pitch of the chain is the total of two spaces adjoining. This pitch distance is measured in a straight line forming one side of a polygon having as many sides as the sprocket has teeth, and corresponds to the older and now less used circular pitch as applied to spur gears. In circular pitch the gears were measured from center to center of tooth, just as sprockets are measured, these measurements being taken on the pitch line. In the later and more common method of measuring gears, the pitch is expressed by the diameter of the gear at the pitch line. Thus, an eight-pitch gear has eight teeth on its circumference for each inch of diameter. The pitch line of a gear is about midway of the tooth and is the line common to both gears; similarly the fixed line of the sprocket and chain is the line of the rivet centers as the chain lies upon the sprocket.

Although less applicable to belting, the pitch line of a belt is approximately at its center and should be taken into consideration when considering pulleys for belt driving.

In some vehicles more than one chain is used, either from the motor shaft to the counter shaft, as in the Holsman,—which employs chains for its change-speed device—or as in many forms of large vehicles which employ two chains from a counter shaft to the rear wheels. The counter shaft is parallel to the rear axle but in front of it, and is fitted with a sprocket on each end, in line with the large sprocket on the corresponding rear wheel. This construction is usually applied to heavy vehicles, and in this construction the balance gear is in the counter shaft and power is frequently transmitted from the change-speed gear to the balance gear by propeller shaft.

Chain troubles usually consist of broken links or sheared rivets, due quite frequently to something getting between the chain and sprocket and thus subjecting the chain to undue strain. If the chain is quite loose, it may climb on top the sprocket teeth with the same result. As the chain wears and increases its pitch length, the tendency to climb the teeth is increased and it will run with a grinding noise, indicating rapid wear. A block chain can usually be reversed with good results after it is partly worn. Extra links are usually carried for repair purposes, and some chains have their rivets buttonholed into the side links, while in others the rivets are held by cotter pins, so as to permit quick repairs to be made.

Chains have been condemned because they have been abused, whereas if properly designed, cased, and cared for, as is necessary with gears, they will give as good or better service.

The propeller-shaft transmitting device is so named because of its resemblance to the shaft used to transmit power from the motor to the screw propeller in boat service. At its forward end it is driven by the motor or change-speed gear just as in a launch, while at the rear end it is fitted with bevel gear usually of small diameter, meshing into a larger bevel gear on the rear axle or counter shaft at right angles to the propeller shaft. In some cases a worm gear is used instead of the bevel, while in others equivalents having pins and rollers instead of teeth are employed, the aim being to reduce the friction of the bevel gear. The bevel gears are commonly encased to hold oil and keep out the dirt, and this casing contributes very largely to the good service given by such gears. In all bevel gears there is a decided thrust against the bearings, which must be strongly resisted if the gears are not to become separated at their pitch line, causing increased noise and friction.

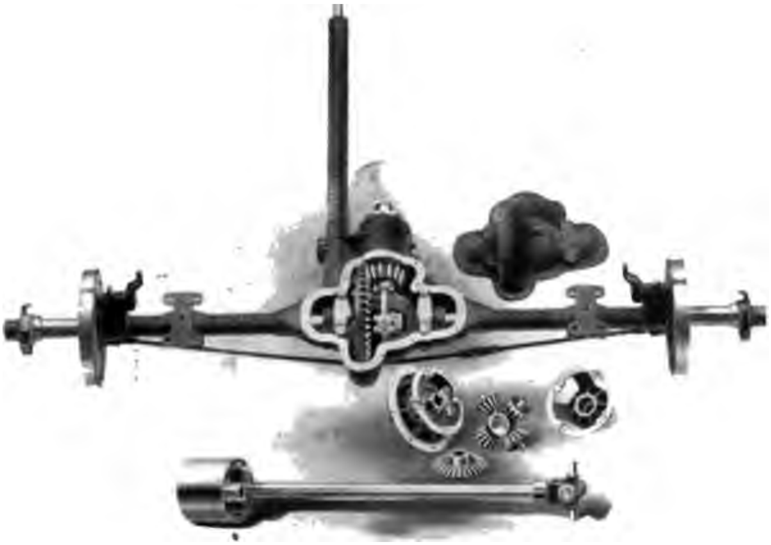


Fig. 39. Propeller Shaft Transmitting Device.

Gimbal Joints. Because of the impossibility of holding the motor at the front of the propeller shaft and the gears at the rear in alignment with each other, it is common to provide the propeller shaft with knuckles or gimbal joints, which, while transmitting power perfectly, permit the shaft to yield and change its direction ten or even twenty degrees. The propeller shaft is usually provided with a telescopic joint which permits it also to vary in length between ends, and these two accommodations allow the springs of the vehicle to perform their function without interfering with the transmission of the power. A great variety of gimbal joints have been employed and the same is true of the telescopic joint. These joints are frequently encased in leather cases packed with hard grease, which both keeps out the dust and insures lubrication.

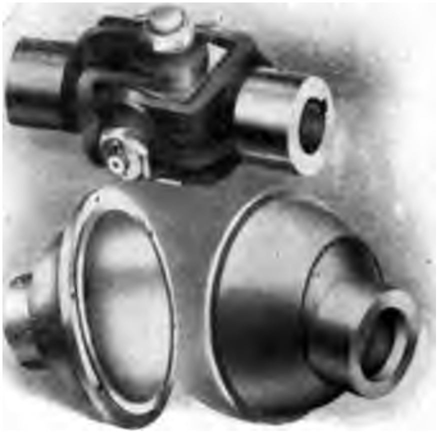


Fig. 40. Gimbal Joint.

Radius Rods. The propeller shaft is frequently paralleled by a torsion rod or bar having sufficient stiffness to resist the push of the bevel gear as it transmits the driving effort to the axle. In any event, this strain must be resisted by some means, and in connection with chains it is manifested as a forward pull parallel to the chain, which is taken by distance or radius rods arranged to extend from the driven axle to, or nearly to, the driving one. In some faulty con-

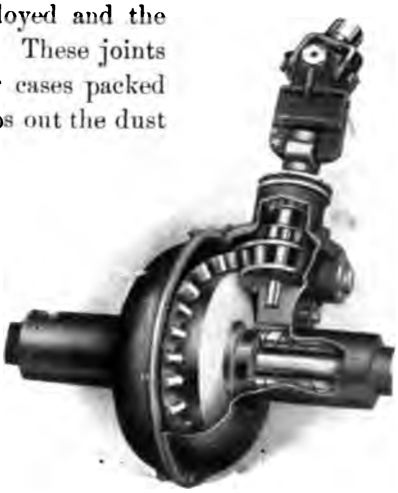


Fig. 41. Roller Bevel Gears and Universal Joint.

structions the distance rods are attached at one end or the other some distance away from the axle centers with the result that the spring action gives rise to a travel of the axle not coincident with an arc drawn around one axle center and passing through the other, and the result of this lack of proper movement is either to loosen the chain or tighten it, resulting frequently in the chain running off or being strained so forcibly as to break it.

Balance Gear. The balance gear, frequently called differential, or jack-in-the-box, is a device intended usually to transmit the power from the sprocket or bevel gear to each half of the countershaft or rear axle and thus to each wheel equally at all times, regardless of whether the wheels are turning at equal speed on a parallel course, or one slower than the other, as in turning a corner. In its simplest form it consists of two large bevel gears attached one to each half of the rear axle, which carries at its outer ends the driving wheels, or in the case of the countershaft, the sprockets for the side chain. Between these large bevel gears is journaled the driven sprocket or driven gear, the hubs of the bevel gears forming the hubs in many cases. In this sprocket or gear are one or more pinions, usually three or four mounted substantially upon spokes and arranged to mesh into the large bevel gears of the balance gear.

In theory each of these pinions is simply a lever receiving the pull of the chain at its center and because its ends (opposite teeth of the pinion) engage the opposite bevels, it transmits half of the pull received to each of the bevels. When the vehicle runs on a straight course the pinions and bevels revolve as a solid mass without relative motion, but if, as in turning a corner, one bevel and its corresponding rear wheel takes a slower motion, that end of the lever (pinion tooth) is retarded, while the opposite end of the lever (pinion tooth) moves forward more rapidly, driving the outer wheel of the vehicle with increased speed. In all cases the amount of force applied to each wheel is the same, since both ends of the lever are of equal length, the only variation being a slight loss by friction, due to the motion of the parts of the gear in relation to each other. While the bevel gear is the simplest form, many balance gears are constructed by the use of spur gears because spur gears are manufactured more cheaply. In this form each half-axle is fitted with a spur gear, while the sprocket is provided with studs or bearings parallel to the axle on which are journaled long spur pinions, usually of small diameter. At their inner ends, these pinions mesh into each other, but one projects to one side of the sprocket, the other to the other side, and these projecting ends mesh into the spur gears. The power transmitted to the sprocket is, by the teeth of these pinions, transmitted equally to the spur gears in which they mesh, while variations in speed are met by the rotation of the pinions in opposite direction, which accomplishes the same result as the rotation of the bevel pinion.

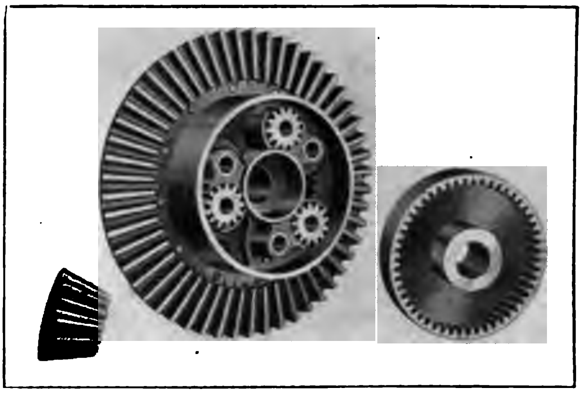


Fig. 42. Spur and Internal Balance Gear.

A third form of this device now little used, employed a spur gear on one half axle, an internal gear of larger diameter on the other half, with a single spur pinion meshing into both and mounted on a stud projecting from the sprocket. The pull of the sprocket was transmitted by this stud and pinion equally to the large internal gear and the small spur pinion, but since the point of application or pitch line of the internal gear was farther from the axle center than the pitch line of the spur gear, the effect was to drive the one wheel more strongly than the other. This arrangement is particularly advantageous where the resistance to be overcome is greater on one side of the vehicle than on the other, as for example in the three wheeler having the third wheel arranged to track with one of the drivers, for it differentiates or transmits the power in different proportion, whereas the usual form being balanced, is really a balance gear.

Other devices are in use to transmit power to both wheels, as is necessary to secure traction and a forward movement without a tendency to shift to one side, and most of these aim to avoid the balance gear. The objection to the balance gear aside from its cost and weight is principally that if one wheel strikes a slippery spot, as a piece of ice, and slips backward, no power is transmitted to the other wheel and propulsion ceases. This is because the slipping wheel moves at double the angular velocity of the sprocket instead of at the same velocity as would be the case if both wheels were revolving at the same rate of speed.

In one or more types of friction-drive vehicles two driving discs are used and no balance gear is employed, it having been found that the friction discs will slip sufficiently to permit satisfactory turning, while on the other hand, if one vehicle wheel slips, the driving ability of the other is in no wise lessened. In the rope-driven Holsman, and one or more of its type, the slip of the driving ropes is utilized in a similar manner. The Hedgeland solid axle not only does away with the loss of strength or the increase of weight, due to the use of half axles, but it secures a positive drive to the slow wheel and thus avoids loss of traction by the slipping of one wheel. In this device each end of the axle is provided with a clutch fitted to the wheel hub so as to remain free when the wheel moves faster than the axle or when the axle stands still with reference to the frame of the vehicle. A forward movement of the axle causes the [illegible] grip the wheel and drive it forward, but at all times

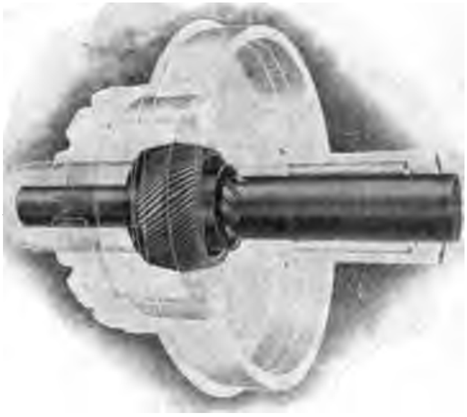


Fig. 43. Hedgeland Solid Axle.

the wheel is free to turn with greater angular velocity than the axle and thus releases itself.

In reversing, the same action results in the opposite face of the clutch being brought into service, while in coasting the vehicle runs free without the necessity of turning the rear axle and propelling mechanism.

Rear Axle. Directly connected with the balance gear is the design and construction of the rear axle. A quite common form consists of two half axles passing through the tubular half frames, which are bolted together around the balance gear forming the balance gear box, frame or spider. Each half axle is a duplicate of the other as in each half of the rear framework, and each is provided with bearings at the inner end near the balance gear and at the outer end adjoining the vehicle wheels. In some construction the balance gear is not exactly at the center but is at one side, making one of the rear axle parts and the tubular portion of its case shorter, while the opposite parts are correspondingly longer.

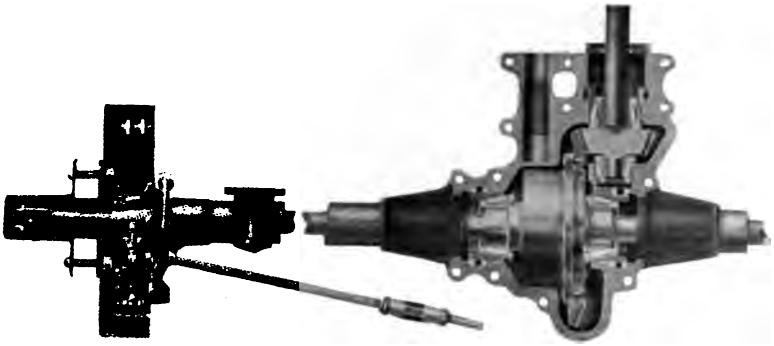


Fig. 14. Rear Vertical and Horizontal Views of Shaft-Driven Rear Axle.

A second form of axle employs a full length axle, having fixed, generally near one end, one of the balance gears, while slipped over this end, is a sleeve, carrying the other balance gear. The outer end of the sleeve on one side and the outer end of the axle on the other are fitted to the corresponding vehicle wheels. A nut on the sleeve end of the axle holds the sleeve in position, and sometimes also holds the wheel in place, the whole forming a simple and satisfactory construction. Both of these forms are what is known as "live axles," *i. e.*, axles which revolve with the wheels. They are advantageous in that the use of a single sprocket is permitted, and this may be placed in under the vehicle, thus bringing the chain away from the dirt of the wheels, where it is less unsightly and more durable. The disadvantage of the live axle is that it must be quite strong to properly carry a given load, because in revolving it is subjected to stresses in opposite directions, and is therefore likely to be broken.

Dead axles are commonly used on heavy vehicles, and these are substantially the same as on horse vehicles. With this construction each driving wheel is fitted with a sprocket from which a chain runs, usually forward, to the projecting end of the countershaft. The balance gear and axle constructions heretofore described, apply, with slight modifications, to the countershafts, which, because of the gear reduction between the countershaft and the rear wheels, need differ only in that they are not so strong and heavy.

Front Axle. The front axle of a motor vehicle differs usually from horse vehicle construction in that there is no fifth wheel at the center of the axle about which the axle turns for steering purposes, although this construction is sometimes used; but generally each end of the axle is provided with a steering head into which a vertical spindle or neck is journaled, which neck carries the axis of the corresponding front wheel. To this neck is attached one or more steering arms for controlling the direction of the neck; and that the opposite wheels may be steered in unison, an arm on one side is connected with a corresponding arm on the opposite side by a tie-bar parallel to the front axle.

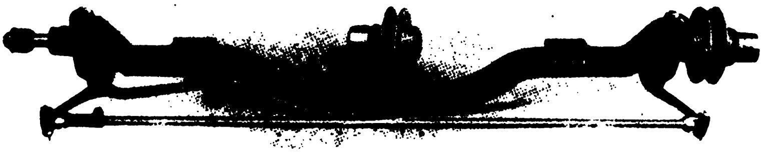


Fig. 45. Complete Front Axle Showing Steering Heads and Tie-Bar.

It is readily seen that in turning a corner both front wheels should be so turned that each will describe an arc concentric with the arc of the other, for if both arcs are not concentric, one wheel or other will be forced to slip sidewise to a greater or less extent, with the result that the tires will be worn and the steering will sometimes be controlled by one and sometimes by the other wheel, with consequent greater skidding and a very disconcerting eccentricity in the matter of steering. The same result is found in driving straight ahead if the steering wheels are not parallel to each other as they should be.

To insure that the steering wheels describe concentric arcs, the steering arms are projected either backward and inward from the steering neck or forward and outward, and the tie-bar is made of suitable length to hold the wheels parallel for straight ahead driving. This arrangement insures that the inner wheel on a turn will be steered at a greater angle from the center line of the vehicle than the outer wheel, and will describe an arc of a circle of shorter radius than the outer wheel. It is quite evident that both wheels should steer around a common center and that the radius for one wheel in one case must be the width of the vehicle, usually about 5 feet, greater than for the other wheel. The proper angle for these steering arms depends upon the distance between the axles and the distance between the steering head center lines, and is found approximately by drawing a line through the steering head center to the middle of the rear axle.

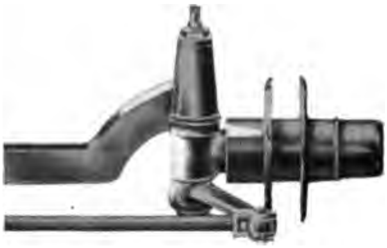


Fig. 46. Front Axle with Lemoine or L Head.

Steering Heads. Steering heads are of several varieties according to the ideas of the designer. The simplest form is an L-shaped forging welded to the end of the straight front axle, the other member of the L projecting upward or downward, and in either event bored to receive the steering spindle. This is quite frequently termed the Lemoine type. A second form provides the axle with a T head, the extremities of the T being turned at right angles, so as to form lugs through which the steering pivot pin passes. This also passes through the steering neck fitted between the lugs. This form is commonly termed the Elliott type. Recognizing the advantage of having the steering pivot as close to the spokes as possible, several makers made these projecting lugs very long, and in place of the vertical neck a curved C-shaped neck was provided carrying the spindle at its center, while at its ends short pivots or screws attached it to the lugs mentioned. This arrangement permits the use of a long wheel spindle and although slightly more expensive to build, and not quite so rigid as the other types, was used because of its merit by Haynes for a number of years.

In any steering device, the object is to have the steering pivot close to the wheel, so that the leverage of the wheel is extremely small, on which account obstacles do not have much tendency to deflect the course of the wheel. Any one who has watched the long pole of a horse wagon sway violently as the front wheels strike an obstacle, can realize how impossible it would be to control a motor vehicle by the arm of an operator unless a considerable mechanical advantage is gained in some manner, and placing the steering centers nearly or quite in the plane of the wheel, secures this advantage to a more or less complete extent.

Some vehicles are equipped with hubs of such size that the steering pivot may be placed exactly in the plane of the wheel, the wheel bearings being of larger diameter than the length of the steering pivot. Other vehicles use forks astride the wheel with the steering pivot over the wheel as in cycle construction. Both of these methods remove all leverage from the wheel, so that there is no tendency to deflect to one side or the other when it strikes an obstacle; but the large hub is objectionable and the long fork with the long framework necessary to get above the wheel is both costly and weak. The advantages of these constructions can practically be secured without additional cost or disadvantage by inclining the steering pivot so that the steering pivot center line strikes the ground at the same point as does the wheel. This construction is used on a number of vehicles at present and its merits will eventually force it to be used by all.

A few vehicles have been steered by the single kingbolt and fifth-wheel arrangement used on horse vehicles, in connection with a worm and segment for turning the axle about this pivot. This form is common in vehicles which both drive and steer by the front wheels, and is quite practical if means for steering by the power of the motor is provided. In order that the worm may have the power required it is of slow pitch and needs many revolutions to effect the desired steering, which rapid movement is not easily made by the operator. A device is easily provided, however, so that the motion of the motor drives the worm in either direction at will and accomplishes the desired result.

A double form mounts both front and rear axles on fifth wheels and swings them in opposite directions, thus steering both ends of the vehicle.

Front axles are usually solid, although sometimes made tubular for the purpose of saving weight. A single tie-bar between the steering arms is commonly used, but for the purposes of safety double ones are sometimes provided.

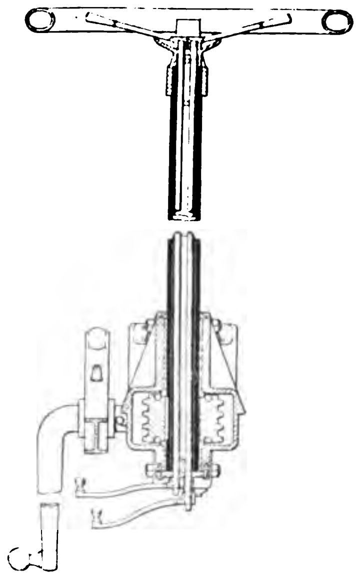


Fig. 47. Steering Wheel.

Control. In order that the front wheels may be controlled by the operator a number of means are used, the most common of which is known as wheel steering. This consists of a rotatable post fitted with a wheel at its top end and with a crank, pinion, or worm at its lower end. Where the crank is used a connecting rod connects the outer end of the crank with one of the steering arms which project from the steering head. Turning the wheel to one side a quarter turn throws the steering wheels to their limit in one direction from the center position, and a similar opposite turn throws them in the opposite direction. As commonly arranged, the post is turned in the same direction as are the steering necks, so that the rear of the steering wheel moves in the same direction as the rear of the front wheels of the vehicle. In the earlier forms the steering post was vertical, but it is now considered advisable to incline the post backward at the top so that the operator's seat need not be so nearly over the front axle. The front end of many vehicles is now utilized for the motor and as the wheels are steered, the front of the vehicle moves to one side or the other in a manner not found in horse vehicles and not conducive to comfortable riding. This objectionable feature is not found farther back, on which account the passengers are usually carried nearer to the rear axle. In some vehicles, the vertical post is equipped with a tiller or rearwardly projecting lever. This was formerl

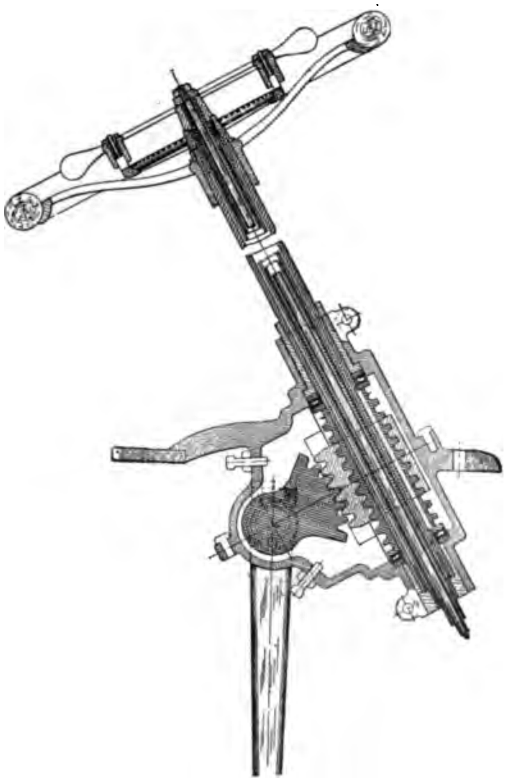


Fig. 48. Steering Wheel Showing Throttle and Spark Levers.

used on light vehicles and is a simple, natural method of steering, but not so satisfactory as other methods.

In other instances, the vertical post stands at the center of the operator's seat or at one side thereof, while the steering lever projects across the vehicle in front of the operator. This gives a powerful method of steering and is preferred by many to the tiller steering.

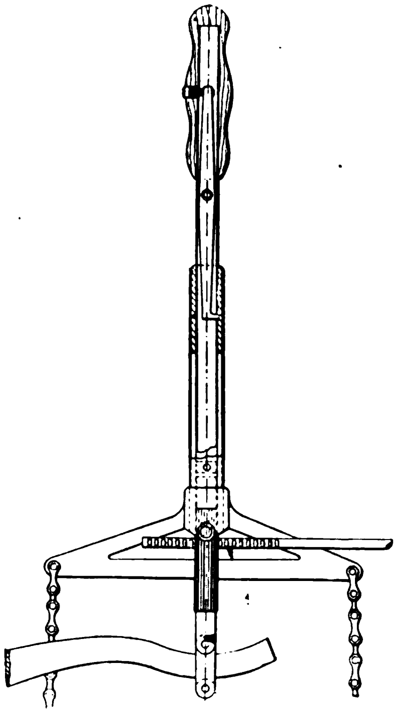


Fig. 49. Duryea Controlling Lever.

Swinging the lever sidewise pulls the chains and steers the wheel. Sliding the handle up or down shifts the lever setting either the high or low clutch. Twisting the handle shifts the rack which controls the throttle.

In order to get still greater power, double levers or handle bars have been used, but the preferred method is the wheel operated by both hands in connection with the worm or pinion at the bottom, by which arrangement the rotation of the post is not confined to a half revolution but is usually arranged to make nearly two revolutions and in some cases more, in order to turn the steering wheels through their extreme movement. It will be understood that the pinion meshes into a sliding rack attached to the proper end of the connecting rod, and that the amount of movement of the front wheels depends upon the diameter of the pinion.

When a worm is used the arrangement is slightly more complex, there being usually a segment of a gear adapted to mesh into the worm, so that a quarter revolution around the center of the gear is produced by the two or more turns of the steering post. Attached to this segment is an arm connected usually by ball and socket joint to the connecting rod. The advantage of this construction is that the worm locks the front wheels of the vehicle in position, against deflection by obstacles or causes other than the will of the operator. This arrangement is known as lock steering and is preferred by some. The free steering is the more common form, however.

A further form of steering employs a vertical lever carried by a horizontal pivot at the center of the seat near the front, and arranged to swing sidewise for steering purposes. This lever is between the passengers, does not interfere with mounting or dismounting, is in position to be operated by either passenger, and is much liked by those who have used it as well as other methods. Being patented, it is employed on one make of vehicles only.

Brakes. Second only to ability to go is the power to stop, on which account the brakes are most important. A wide variety of these have been used in the past but practically all have been abandoned excepting band brakes. A tire brake consisting of a shoe bearing against the tire of the wheel is considered detrimental to the tires and does not hold well on wet rubber. Band brakes are applied to the countershaft, to the rear sprocket, to the large gears of the balance gear and to the hubs of the wheels. They are of two varieties,—internal or expanding bands, and external or contracting bands. In the earlier form the external band was commonly used, one end being fixed to the frame of the vehicle, while the other was attached to the operating lever. Application brought the loose end in contact with the revolving drum which caused the band to tend to wind itself around the drum, forming a very effective brake without requiring a great amount of power for operation. This form was faulty when running backward because the friction of the loose end of the band against the drum tended to release the band, with the result that brakes of this kind hold well in one direction but not in the other.

Most forms of band brakes now are attached at the middle of the band, leaving both ends for operation. This insures that no matter which way the vehicle is moving, the brake is equally powerful. In one or more forms the band is provided with two points of support, one of which takes the strain in a forward direction, the other in a reverse and when both ends are equally operated upon, this form of brake is particularly powerful and [illegible] the slightest effort on the part of the operat[illegible] [illegible] self applying. On the heavier vehicles [illegible] are sometimes applied to the same drum affixed to the hubs. This utilizes double the surface and gives enormous braking power. Many varieties of arrangement are found, but the general principle is the same. Brakes are usually operated by foot levers, but many vehicles have also a hand lever.

Two methods of braking are considered good practice, and most vehicles can be stopped by throttling the engine or applying the proper clutch, so that even if only one brake is used, a second means of control is always present. Some makers believe it is better to fit one brake only, in order that the user, by using it daily, may not only know its condition, but may be trained to use it instantly and automatically, because it has been found that in emergencies the operator forgets special features like an emergency brake, and fails to use them even though he had depended upon them to the neglect of the condition of the more commonly used brake.

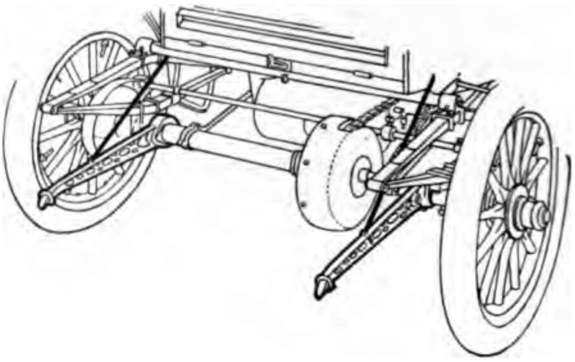


Fig. 50. Drop Brake.

To prevent movement backward in case of failure of the brakes, a sprag is commonly used. This is hinged to the rear axle of the vehicle and is let down at the bottom of the hill so that it drags, forming a pawl, which at the first backward movement of the vehicle digs into the ground, effectually stopping movement backward. Some vehicles have the wheels provided with ratchet teeth and a pawl to engage them in the same manner. Others depend on brakes only, but in order that the vehicle may be left standing on a hill, provide the brake levers with ratchet and pawl to hold them when set.

WHEELS

There are few more important parts in a motor vehicle than the wheels. These are sometimes made of steel, much like bicycle wheels, but the earlier forms were made too light, on which account this style of wheel has been largely condemned. The same fact applies to wooden wheels as commonly used on carriages, with the result that the accepted form to-day is the artillery wheel, a construction having wooden felly and wooden spokes with large butts. These butts join each other forming a complete circle of wood at the hub and are gripped between flanges of metal bolted together through the wood. Any loosening of the spokes at the hub is taken up by tightening the bolts. To the wooden felly is attached the metal rim which engages the pneumatic or solid rubber tire. Some wheels are in use having steel spokes and some experiments have been made with springs instead of spokes in the attempt to gain elasticity in the wheel instead of at the tire. The common wheel, however, is the artillery form described.

It is a noticeable feature of motor vehicle wheels that they are much smaller than the wheels of horse vehicles, although the loads carried are decidedly larger. The reason for this is three-fold. Pneumatic tires are costly, so the vehicle maker to save first cost, uses a small wheel with consequently small and cheap tires, and the buyer having no experience assumes that this must be best, after which the maker excuses himself by saying: "The public wants it." Small wheels are doubtless responsible largely for the great tire and mechanical repairs frequently connected with motor vehicles, and also with the lack of practicability on bad roads, in deep snow, and similar conditions, successfully negotiated by horse vehicles. The second reason for small wheels is the fact that the motor runs more rapidly than the wheels, which necessitates gearing, and large wheels require a greater difference in gear ratios than do small ones, thus increasing the difficulty of the builder. A third reason for small wheels is their greater strength, but it seems wiser to use large wheels and decrease the weight of the parts to be carried, particularly over the rough roads found in most parts of America.

Tires. Since motor vehicles depend upon the wheels for propulsion, tires having great traction are necessary, particularly if a large proportion of the load is carried on the front wheels, which must be pushed by the rear ones. On this account rubber tires are practically necessary, because steel tires slip on every bit of ice, on iron rails, and even on hard pavements unless caused to grip by spikes or similar projections, which are both rough and noisy. On some vehicles blocks of wood, presenting the end of the grain to the street, are used instead of tires and are found more durable and less expensive than rubber and less noisy than metal, while giving good traction. For trucks, such tires seem well adapted. Wide heavy tires of solid rubber are also used on heavy vehicles, but the pneumatic tire from 2½ to 5 inches in diameter is the prevailing form. These not only give traction but smooth the road very perceptibly, and are therefore well adapted to high speed. Although many other styles are constantly being tried, such as various forms of arched or cushioned tires, also tires having steel springs for resiliency, the pneumatic tire is almost universal.

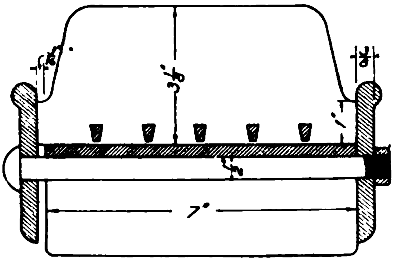


Fig. 51. Solid Rubber Tire for Heavy Vehicle.

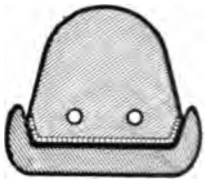


Fig. 52. Solid Rubber Tire for Light Vehicle.

This was formerly most common in the single tube shape, but of later years the detachable tire, consisting of an outer shoe or casing with a removable air tube, has become the favorite. Metal rims are nowadays provided with one side removable, which permits the tire to slip off easily, after which the air tube can be repaired or a patch laid on the inner side of the casing. Three common forms of tires are in use at present.

The Clincher tire is so called because as first constructed, its edges were provided with hooks or clinchers, which engaged similar hooks along the edge of the rim. As now constructed these are practically abutments resting against the upturned edges of the rim, the tire being held down in the rim by its constrictive fabric, which causes it when inflated to shorten in length and grip the rim forcibly. Clincher tires are sometimes held in place more positively by large-headed bolts, which clamp the edges of the casing between the heads and the sides of the rim and prevent the tire from lifting and blowing out of the rim when turning corners at speed, or when partly deflated.

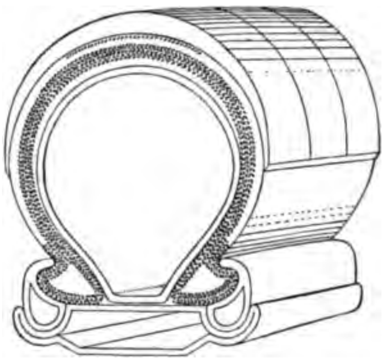


Fig. 53. Clincher Tire.

The wired tire has an endless wire fitted in each edge. This wire is just large enough to pass over the base of the rim and cannot pass over the flange or side when in place. In this form the wire performs the duty of holding the tire to the rim, so that the fabric is called upon only to retain the air pressure within the tire and may therefore be less strained than in the constrictive form where it must both hold the air and also the tire itself, thus performing a double duty. A third form has its edges clamped along the sides of the rim by mechanical means. This is a most positive fastening, effectually preventing creeping, rolling, or blowing off, but it is not so quickly removed for repairs as is the wired tire with removable flange to the rim.

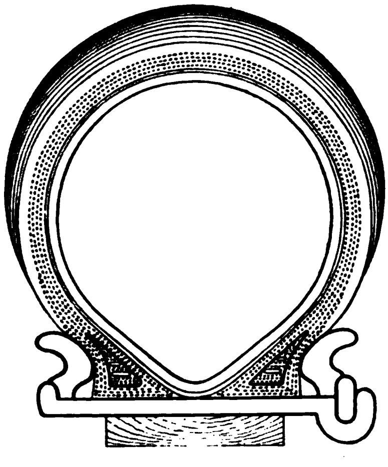


Fig. 54. Wired Tire.

When deflated the removable ring is pushed inward, the bead removed from its groove, after which the removable ring and tire slip off freely.

With tires as with wheels, the size is important. The strength of rubber and fabric is quite limited and a surface sufficiently large to support the load without damage to the rubber, must be provided if the tire is to be durable. The constant bending of the tire in the performance of its duty, wears out both fabric and rubber resulting in bursts and blow-outs, while danger of puncture is always present. These objections are best overcome by the use of tires of small diameter in cross section on wheels of large diameter. In this form the contact on the ground is quite long, thus securing a large supporting surface; the wheel revolves less times per mile, thus bending the tire less often, as well as allowing the heat caused by the bending of the tire to dissipate; and finally, the narrow tire is less likely to puncture, for it does not pass over so wide an area and therefore encounters proportionately a less number of causes of puncture. Further, it meets less resistance from mud, sand and gravel, skids less, and therefore is less damaged than a tire which slips and skids more frequently, because it is abuse rather than use which damages any construction. The tire of large section on a small wheel has a bearing more nearly circular on the ground and slides like a snow shoe easily in any direction and thus contributes to skidding, whereas the large wheel with narrow tire is more like a sleigh runner and less likely to skid sidewise. The large wheel rolls out of depressions easily instead of slipping around in them, and it is believed by many that skidding and rapid wear are largely found under the same conditions.

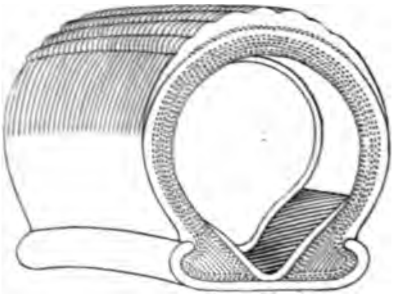


Fig. 55. "G. & J." Tire.

A sudden application of the brake will frequently start skidding, and this is known to conduce to tire destruction. The same remark applies to sudden or jerky applications of the power. On this account the operator should cultivate handling the vehicle smoothly without jerks or abuse. In case of skidding, minimize the trouble by easing the brake or partly shutting off the power, and at the same time swinging the steering wheels, so as to carry the front end to the same side as the rear. Jamming on the brake or shutting off the power suddenly is liable to make the matter worse.

IGNITION.

One of the most important features of the gas engine is the ignition. It is also the most delicate, and therefore the first place to look for trouble when things go wrong. Present day autos make use of one of three systems of ignition and some are fitted with two forms so as to have reserve if one form fails. In America the make and break spark was the earliest form and has been continued by one maker until the present. This form, also called the wipe, touch, contact or kiss spark, employs two electrodes within the cylinder, one of which is usually insulated in a fixed position, while the other is not insulated, but is movable and arranged to come in contact with the fixed electrode and be separated at the moment the spark is required. In some cases the movable electrode is insulated instead, and in still other cases both electrodes are insulated.

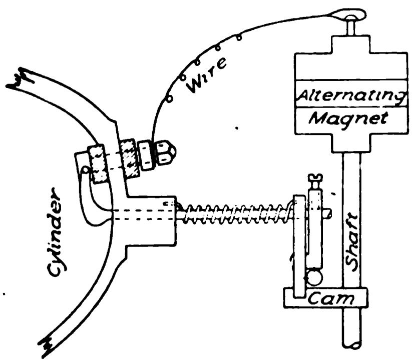


Fig. 56. Make and Break Ignition.

The electric circuit from a battery or other source passes directly through these electrodes, but in order that the spark may be rendered more intense than would otherwise result, it is customary to introduce a simple coil into the circuit, except in such cases as do not need this because of the nature of the generator. The low tension alternating magneto, for example. needs no coil, the windings and core of the armature serving this purpose perfectly. A shunt-wound dynamo will also give a large spark without the use of a coil if the contact is but instantaneous. The coil used with a half dozen cells or with direct-current magnetos or dynamos is identical with that used for lighting gas in dwellings. It consists of a core of soft iron wire, 5 to 8 inches long by about 1 inch in diameter, wrapped with four to ten layers of insulated copper wire $\frac{1}{16}$ inch diameter. When a current passes through this coil, the core is saturated with magnetism, thus storing, as it were, the energy of the current. When the circuit is broken at the electrodes by separating them, the magnetism in discharging from the core induces a very intense current in the coil, which jumps the gap between the electrodes, making a spark so intensely hot that even heavy cylinder oil is varporized and any reasonably explosive mixture is ignited with certainty.

The movable electrode is operated by any suitable mechanism, which differs in different designs, but it is a common practice to bring the points together by a strong spring and to separate them by a blow as from a hammer. The coil used must both charge and discharge quickly in order to be suited to high speed work, and since the spark is caused by the discharge, the points must be separated far enough (nearly ⅛ inch), to give ample room for the spark before the strength of the discharge has been spent, so that in this, as in the vibrator of the ordinary jump spark coil, a sharp, quick break is an essential feature. The moving parts must also be light in order that they may move quickly. The merits of this system have compelled recognition from the best makers and it now seems likely to supersede the jump spark on high grade vehicles.

In France the jump spark was used as early as 1862 by Lenoir, and later by Benz in Germany. It was brought to its most successful form on high speed motors by DeDion and Bouton about 1896 and its success on the many little tricycles turned out by this concern gave it an impetus into public favor, which it has largely since retained. In this system the two electrodes are both fixed. generally in the form of a plug which may be screwed into the wall of the cylinder. Usually one electrode only is insulated, but both are insulated in some cases and connected to the two high tension terminals of the jump spark coil or transformer. This coil is quite complicated and consists of a primary winding, forming part of a primary circuit—the equivalent of the circuit employed on the make and break system—a condenser connected across the primary circuit on opposite sides of the circuit breaker, and a secondary coil

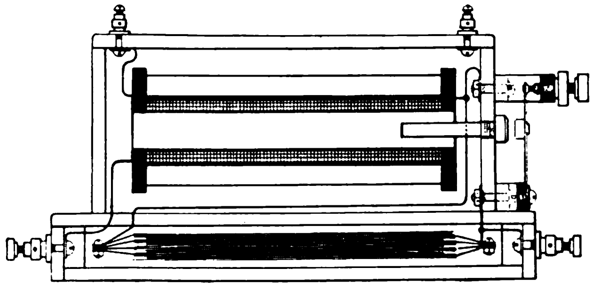


Fig. 57. Section of Jump-Spark Coil.

parallel to the primary, but much longer and of finer wire. The theory of this coil is that when a current is passed through a wire it will induce a current in another wire parallel to the first. When the circuit is broken, the core of the coil being saturated and discharging, as in the primary coil, induces a very strong electric impulse in the long secondary coil, with the result that a spark will jump a considerable gap between the electrodes to which the terminals of the secondary coil are connected. Because of this ability to jump, the system takes its name. In the primary circuit of both systems, the induced current tends to jump where the circuit is broken, but in the secondary circuit the induced current must jump the permanent gap because the terminals do not move.

In order to avoid the large spark at the breaker or vibrator in the primary circuit, a condenser consisting of many layers of tin foil insulated from each other by waxed paper, is arranged with alternate sheets connected to the terminals of the primary circuit on opposite sides of the circuit breaker. This device in effect prevents the discharge of the core from expending itself by producing a current in the primary circuit, and therefore increases or condenses the spark in the secondary circuit.

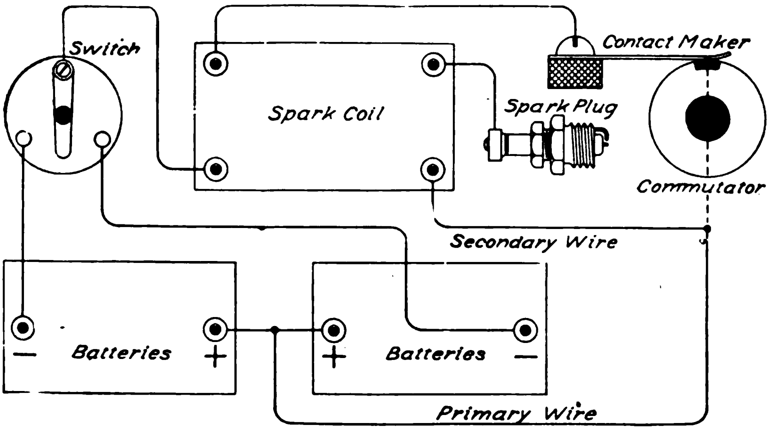


Fig. 58. Wiring Diagram of Jump-Spark Ignition.

In the simplest forms of jump spark ignition, the primary circuit breaker is operated by the mechanism of the engine, which causes the primary circuit to be broken when the spark is desired, just as in the make and break system. Since, however, better results are obtained by closing and breaking this circuit at a certain rate of speed, than at other rates, it is now most common to employ vibrator coils which have a spring arranged to close the circuit and employ the magnetism of the coil to attract the spring, when the core is saturated, and thus automatically break the circuit, resulting in a continuous vibration or buzzing with an accompanying stream of sparks. With this arrangement it is necessary to break the primary circuit in order to stop the sparks when not wanted, and to this end a timer is operated by the engine instead of the mechanical breaker. By means of this timer the current is connected at the proper time and the vibrator produces one or more sparks, one only at high speeds and several at very low speeds, as when starting. This timer is usually adjustable so that the circuit may be connected earlier or later as compared with the movement of the engine by which arrangement it is possible to produce the spark as desired, either after the piston has passed the dead center, or more or less before the dead center, in some cases 45 degrees ahead.

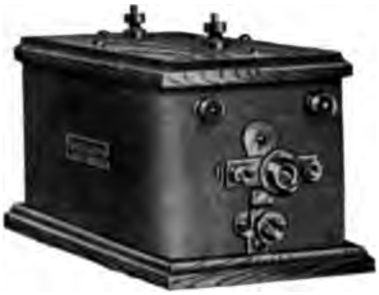


Fig. 59. Jump-Spark Coil.

The object of this advancement is two-fold. The jump spark is so small that the ignition of the explosive charge begins slowly. Second, the time required by the vibrator after the primary circuit is connected, is dependent upon the adjustment of the vibrator but may be such part of a second (usually .004 to .005) that the crank shaft will have moved 5, 10 or even more degrees of angularity before the spark takes place. This lag is particularly noticeable when the vibrator has just broken connection as the timer made connection, the result being that the spark cannot occur until the vibrator spring has made one movement and swung back into contact long enough to charge the coil.

This condition frequently exists with the result that ignition takes place at various times instead of at a fixed point, as with the make and break, and the position of the timer does not represent the average ignition position but rather the advanced position with average cases much behind and extreme cases still more so. Recognizing this effect, jump spark users are, to some extent, employing a single coil on multiple cylinder engines and distributing the secondary spark from one plug to the next by a well insulated commutator or distributor, so that the average position of ignition may be the same on all cylinders. If separate coils with separate vibrators are used, the difference in the vibrators causes a different average position of ignition and since the multiple point timer cannot be adjusted for one cylinder independent of another, the result is a slight difference in the strength of operation of the different cylinders.

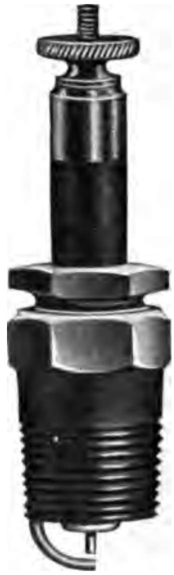


Fig. 60.
Jump Spark Plug.

Since the secondary or high tension current of the jump spark system is of sufficiently high voltage (10,000 to 25,000) to jump the gap between the electrodes while the charge is under compression, it will jump a very large gap in the open air, and must therefore be very carefully insulated. Rubber covered wire ½ inch or more in diameter is commonly used, the wire itself being very small. The plugs are usually of glazed porcelain or of tightly rolled mica or in some instances, of lava or other heat resisting materials. The gap between the electrodes or spark points is usually $\frac{1}{32}$ inch, or slightly more, and a spark to successfully ignite, under the influence of the resistance of the compressed charge, should have sufficient energy to jump ⅜ or ½ inch in the open air. A leakage of electricity from the high tension circuit can usually be seen in the dark by a slightly luminous brush-like discharge, and indicates a point where the insulation should be improved if the best results are desired.

A third system, which has attained some prominence recently, is the magnetic make and break, commonly called the magnetic plug. In this device the magnetism of the primary coil or of an auxiliary primary coil is used to separate the movable electrode from the fixed electrode instead of the separation being made by mechanical means. A timer is necessary in the circuit for the circuit is commonly closed and must be broken by the timer to prevent a continuous succession of sparks. The fault of this device is that it is not well adapted to currents of varying strength, as for example, the current from a generator driven by the engine; because in starting, the engine cannot be turned fast enough to produce a strong current and the magnetic plug will not operate, or if adjusted to operate on a weak current, it operates continuously on a small saturation of its magnet and breaks the circuit before the core is properly saturated as is required for large spark. To overcome these defects, a two circuit device has been used, both primmary, and not complicated. One circuit operates the make and break while the other is a sparking circuit pure and simple. The magnetic plug is believed to combine to a large degree, the good features of both the make and break and jump systems and with suitable development will doubtless have a large future.

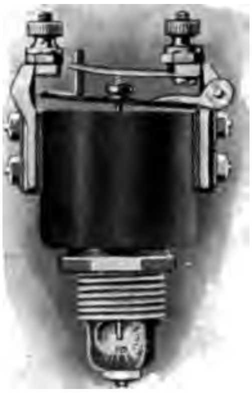


Fig. 61. Magnetic Spark-Plug.

The hot tube ignition used by Daimler and others until the beginning of this century is now seldom found.

Galvanic Cells. The earliest source of current was galvanic cells employing a liquid electrolyte. These were sloppy, short lived and very unpleasant to handle, because of the nature of the electrolyte, which was either sulphuric acid, caustic soda, sal ammoniac, or something of this nature. Such batteries have been replaced by dry cells packed solid and simply moistened with a sal ammoniac solution. These are not likely to leak even when placed on their sides because of the small proportion of liquid contained by them. They are cheap in price and because of their use in telephone service, are purchasable almost everywhere. They deliver their output under a tension of one to one and one-half volts and therefore require a less number in series than most wet cells. The ordinary make and break coil is designed to operate with from 6 to 10 volts and 2 or more amperes, although very satisfactory results can be obtained with much less. The jump coil is usually wound for four to eight volts and gives best results if the amperage is quite large. Four to six cells in series is the customary battery, and good practice makes use of two or more series alternately until all are perceptibly weakened, after which two series are connected in parallel or multiple which doubles the strength (amperage), while maintaining the proper voltage. As the voltage of the cells decreases, connecting an additional cell in series is advisable.

Some users prefer storage cells known as accumulators or secondary batteries. These cells deliver two volts each, and since the internal resistance is low, they will deliver a large quantity of current and thus make a strong spark. They are prepared in small sets suitable for ignition purposes, giving four to ten volts, and although heavy, are quite reliable. Their first cost is greater than dry cells and the cost of recharging is frequently as much as a new set of dry cells. They are probably most satisfactory when used in connection with a direct current magneto or dynamo, by which they are kept fully charged and able to give a strong spark.

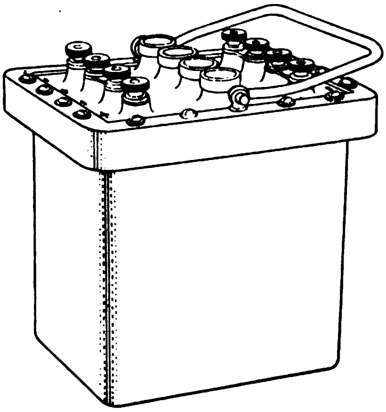


Fig. 62. Accumulator for Gas Engine Ignition.

Mechanical Generators. An early form of mechanical generator was a small shunt-wound dynamo. These are used to a considerable extent and not only give large sparks for both the jump and make and break systems, but also serve to charge batteries, light electric lamps, operate magnetic clutches and even operate magnetic horns.

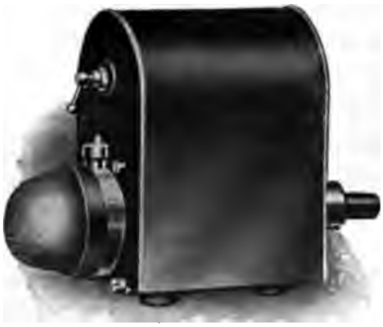


Fig. 63. Direct-Current Magneto.

The most common form of mechanical generator is the direct-current magneto, which differs from the dynamo in that the field is composed of permanent magnets. These generate current at lower speeds than the dynamo and the current does not increase in quantity with the speed to so large an extent, on which account it is better adapted to the varying conditions of auto work.

It is customary to drive these direct-current generators by friction pulley in contact with the fly-wheel, and some form of governor is provided to withdraw the pulley from contact and thus prevent the generator being driven at excessive speeds, and yet be driven by the small pulley at a speed fast enough to spark when the engine is running slowly. It is quite common to use these devices for starting the engine, but in many cases a battery of dry cells is provided which makes starting somewhat easier.

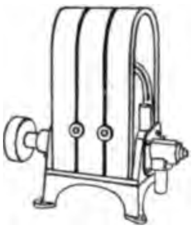


Fig. 61. Alternating Current Magneto.

The alternating magneto will produce two sparks or electrical impulses at each revolution of the armature, and in order that these may occur at the proper time, it is positively driven by gears. This form has no brushes and only one contact from which the live wire is carried. The discharge of the armature serves the same purpose as a spark coil, so no spark coil need be used. As ordinarily made, these are about twice as heavy as the direct-current magneto and will give a spark at as low as 50 or 75 revolutions per minute, whereas the direct-current magneto requires five times this speed to generate a spark sufficiently strong for ignition. Of course, neither magneto will spark properly at such speeds, the alternator usually requiring several hundred revolutions, while the direct-current device or the dynamo are usually driven above 1000.

In case of trouble the brushes or contact points are usually at fault. The contact surfaces will frequently be found dirty and glazed in a manner to prevent the passage of current. Sometimes a bit of iron attracted by the magnetism forms a short circuit across some insulated parts. The bearings should be carefully watched, for if much worn the armature will strike and reduce the speed, or if dry, the friction of the bearings will be greater than that of the driving pulley and the speed will be too low for regular ignition. If the pulley surface is dry, apply belt dressing or a trace of heavy oil; but if greasy, apply powdered common chalk. Resin is sometimes used, but if the fly-wheel surface is hot it is not satisfactory, because it is oily when hot and increases the slipping. These remarks also apply to friction driving gears.

PUMPS.

Pumps are usually one of three varieties, centrifugal, vane, or gear, although reciprocating plunger pumps are occasionally used.

The centrifugal pump is usually 5 or 6 inches in diameter by 1 inch thick, with a revolving vane driven by a shaft which projects through a stuffing box forming one end of the axis of the pump. The water is admitted at a central opening on the opposite side of the case and leaves the case through a tangential opening on the edge. These pumps are not easily clogged, have no parts to wear or be noisy, employ no valves, and do not impede the natural circulation of the water if for any reason they cease running. They are quite usually driven by friction pulley and are generally speeded to 300 revolutions per minute or faster.

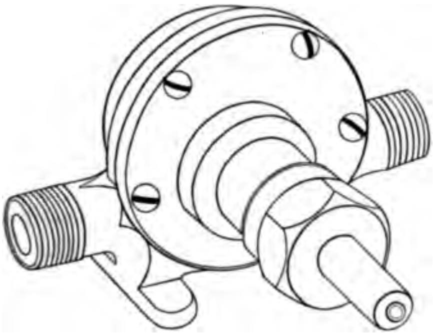


Fig. 65. Vane Pump.

The vane pump is somewhat smaller in diameter but of greater thickness and has the casing eccentric with respect to the shaft. The inner end of the shaft is enlarged concentrically to meet the closest inner surface of the casing, and a slide or vane is forced by the revolution of the shaft alternately back and forth through this enlarged end. This slide is frequently divided at its center and fitted with a spring, which keeps the ends in contact with the inner circumference of the case at all times. The inner and outlet are tangentially placed on either side the contact point of the enlarged shaft end. The vane ends wear rapidly if the water contains grit, and small obstacles are likely to do damage. This form of pump is usually driven by gears or attached directly to the cam shaft or similar part of the motor.

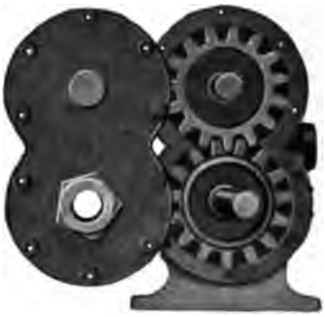


Fig. 66. Gear Pump.

The gear pump consists of two gears of coarse pitch, meshing together and revolving in a figure -8- shaped case, the inlet being on one side of the center, the outlet on the other. The liquid is carried by the tooth spaces around the ends of the 8 but cannot return between the gears because crowded out of the spaces by the meshing of the teeth. This pump has no valves but like the vane pump, is liable to damage if foreign matter is permitted to enter, and it is of small capacity in proportion to its size. These pump shafts are fitted with stuffing boxes to prevent leakage of water around the shaft. Prepared packings are usually supplied for these boxes, but candle wick filled with tallow or other heavy grease is quite commonly used.

Reciprocating pumps employing piston and check valves are sometimes used but not frequently, although common in launches.

Failure of the pump to work is usually manifested by rapid boiling of the water, smoking of the lubricating oil, and in extreme cases, by loss of power, premature ignition, with pounding, and the symptom of stiffness in the engine when turned by the starting crank. An air or steam trap or pocket is often responsible. Drain the system and refill taking care to get out all air. If clogged by solid material the pump must be opened although turning backwards may relieve it temporarily.

AIR FANS.

For air circulation the ordinary screw-blade fan is most common. This is seldom constructed with less than four blades and generally, in order that it may not be of great thickness in proportion to its diameter, it has eight to twelve or even more blades. It is usually mounted on ball bearings commonly run by V or round belts, although flat belts and spur gears are sometimes used.

Next in frequency of use is the practice of making the spokes of the fly-wheel serve as fan blades and thus avoid the fan with its extra parts, high speed, added bearings and extra oil cups. The use of a centrifugal fan or blower has been attended with good results and is advisable where much pressure is preferred rather than large volume of air. In some instances the energy of the exhaust has been used to induce a current of air and cause this to assist the cooling without additional mechanical parts.

Both pump and fan troubles usually arise from failure to be driven, generally because of slipping of the belt or friction pulley, or because some obstacle impedes the movement of the pump or fan. Pumps sometimes cease to work because they fill with steam, which leaks back through the pump as fast as it is forced forward. The remedy is usually obvious and the trouble is noticed when symptoms of overheating in the engine appear.

BODIES.

The bodies of most autos have one common feature, i. e., the operator's seat. This was formerly placed well to the front, as in horse vehicles, but because of the sudden sidewise movement of the front end, due to steering, this seat was found more comfortable if placed further to the rear, and since many owners are also drivers of their own vehicles, the operator's seat is usually at mid-length of the vehicle. The motor, originally under the floor of the vehicle, is now quite commonly placed vertically in front and covered with a bonnet, which utilizes the available space in front of the operator. On this account additional seating room is secured at the rear, over and frequently behind the rear axle. In some vehicles, as in the Orient, and Adams-Farwell, the motor is at the extreme rear, near the rear axle, while the passengers are carried between the wheels as in the horse vehicle ; a sensible and practical arrangment.

The form of additional seats has been a matter of wide difference of opinion. Some early vehicles had a front seat facing rearward. Later the dos-a-dos was considerably used because it permitted an unbroken space, under both seats, for the mechanism. The dust and exhaust gases behind the vehicle would arise unpleasantly in the faces of the passengers and this rendered such seats unpopular. Rear seats oppositely facing were next tried and this form gave way to the "tonneau," having a seat on each rear corner much resembling two water barrels, from whence the name. A door between these seats, opening at the rear, completed this form, but the necessity of dismounting in the street when the vehicle stood alongside the curb, soon destroyed its popularity.

Side door rears with an occasionally a side door front now prevail. This is a much nearer approach to the common horse surrey, and it seems likely that the satisfaction found by horse users will be accepted by auto users and doors done away with except in the heavier and more elaborate vehicles.

Emergency Seats. For temporary increased seating capacity, emergency seats are quite common. The high cost of the auto as compared with horse vehicles makes it necessary that one vehicle should serve several purposes instead of there being provided a variety of vehicles. When the mechamism was carried at the rear, a front seat usually facing forward and arranged with folding foot board and back was quite common, This was directly over the front axle, rode unpleasantly, required lap robs to protect ladies' and children's skirts from the wind, and exposed the passengers to dangers of collision and scary horses, as well as getting them in the way of the operator's vision. Seats facing the rear are still used in large tonneaus and serve well.

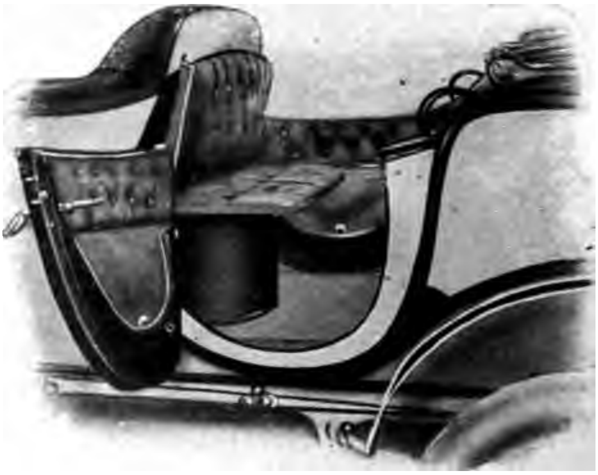


Fig. 67. Arrangement of Extra Seat.

The folding rear has been recently introduced and converts the runabout into a surry in a practical, comfortable and inexpensive manner. Unlike a detachable tonneau, it is always present when wanted, and quickly closed when not wanted. It adds little extra weight, requires no mechanical work to open or close and bids fair to be a permanent device.

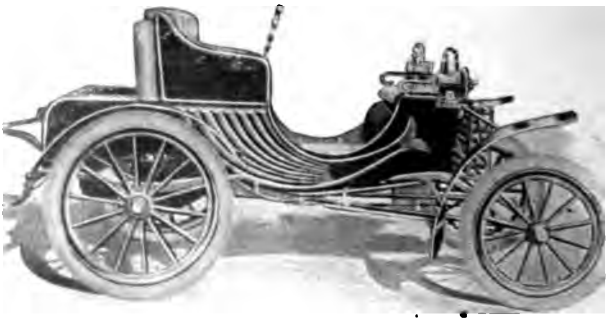
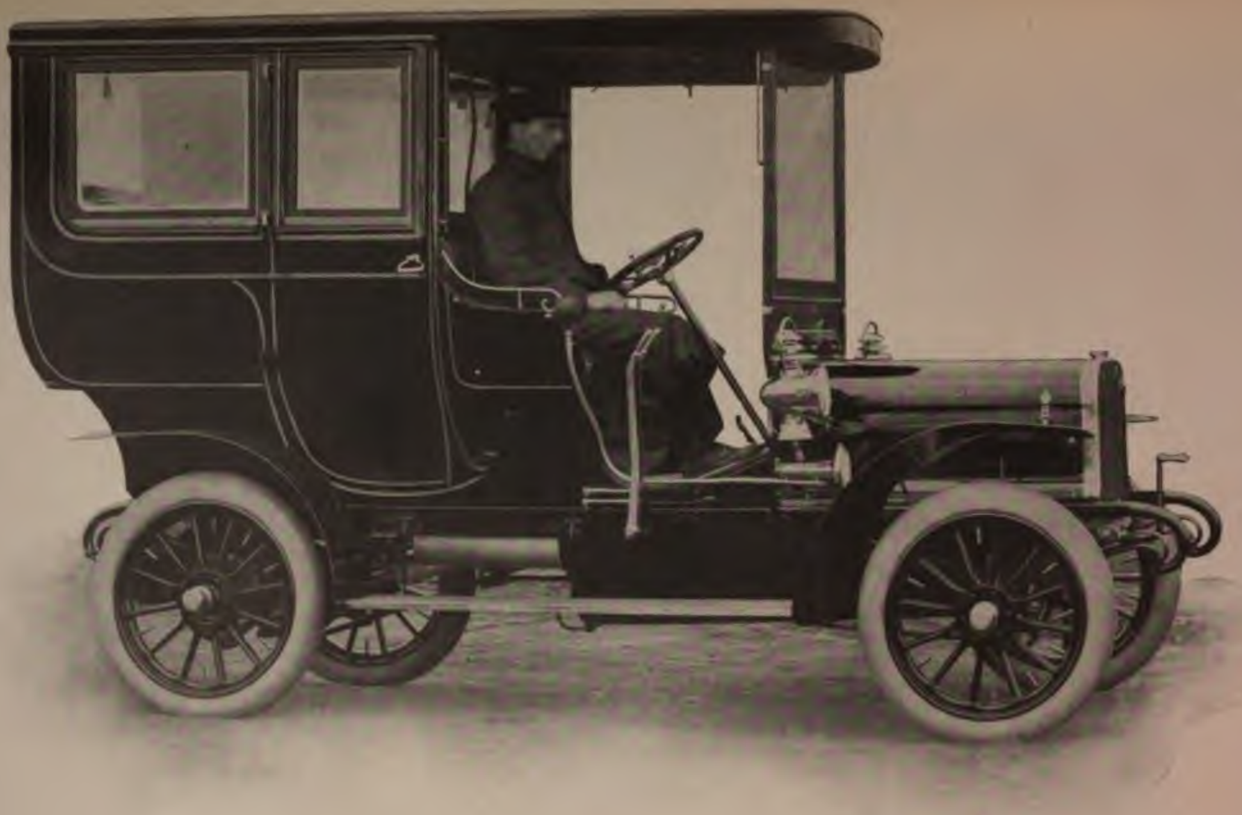


Fig. 68. Folding Rear Seat Phaeton.



LIMOUSINE TYPE OF AUTOMOBILE, 1906 MODEL
The Winton Motor Carriage Co.

THE NEW YORK
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ASTOR, LENOX AND
TILDEN FOUNDATIONS
R L

In some forms of vehicles notably cabs and broughams, intended to be driven by drivers for hire, the operator's seat is at the extreme front or at the extreme rear as in similar horse vehicles. It seems evident that similar requirements will largely dictate similar forms in autos as in horse vehicles, and mechanics will doubtless be able to accommodate the mechanism to the bodies without great deviation from those vehicle forms proved by years best suited to the needs of the public.

Tops. Auto tops are substantially the equivalent of those used on horse vehicles although generally larger and more strongly made. They are either single or double, of the folding or cape top variety, with occasionally a canopy top and quite frequently a standing top with curtains or with glass windows, forming a completely enclosed vehicle. High speeds in cold weather have made some form of protection desirable, so glass plates are fitted in front of the driver and are used either with or without the top as desired. They should be folding or removable because the air carried behind them is dust laden in dry weather and in rain or snow one can not well see through them.

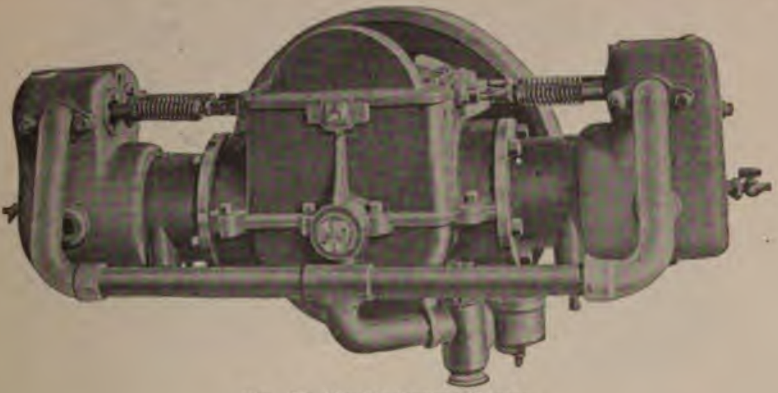

Fig. 69. Double Opposed Motor.

Location of Mechanism. Several arrangements of mechanism are in use. In the earlier forms the motors were placed under the operator's seat because this was near to the driven axle and was the most available space unused by the passengers. As motors increased in size this space was not sufficient, so the body of the vehicle was extended backward, the full height of the seat, giving much additional room. Additional passengers were either placed in front or on top of this rear extension, with the result that, as motors were made still larger, they were crowded down under the floor in a dark and inaccessible position as well as exposed to the mud and dust of the road. These faults compelled recognition, and, coupled with the unpleasant riding qualities of the front end, caused the motor to be placed at the front with the transmission gear and similar fittings under the floor as in common use at present. In a few instances designers were able to provide sufficient power in the space under the seat and thus avoided placing the motor in front, far removed from its point of application of power, and the success of such arrangement with the success of rear-placed motors renders it likely that in the near future the motor at the rear will be considered, as it undoubtedly is, the best engineering practice.

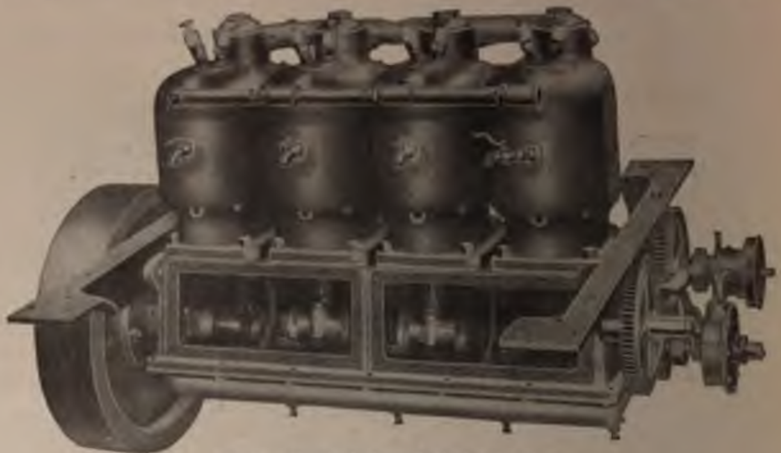

Fig. 70. Vertical Four-Cylinder Engine.

Most designers began by using single-cylinder motors which were placed horizontally lengthwise of the vehicle, because this placing secures low center of gravity and least vibration. Increased power was secured by doubling the cylinders, but since a twin motor of the four-cycle type ignites in irregular sequence if the cranks are opposed, the double opposed motor became the accepted two-cylinder form. This ignites one cylinder each revolution instead of one and one-half revolution followed by one-half revolution apart, as in the twin-cylinder type.

Doubling the twin motor gave the common four-cylinder engine, usually placed vertically, with crank shaft lengthwise the vehicle. The reason for this arrangement is that the width of an ordinary vehicle is not sufficient to place the motor crosswise, with crank shaft parallel to rear axle, as in the single and double cylinder arrangement. The triple cylinder motor is used by some makers who believe that it secures multiple cylinder results with the least complication and is therefore the most desirable form. Such engines, with cylinders of 5-inch bore, are placed crosswise of the vehicle as in the Duryea while four cylinders of nearly 4-inch bore are placed crosswise at the front in one or two air cooled

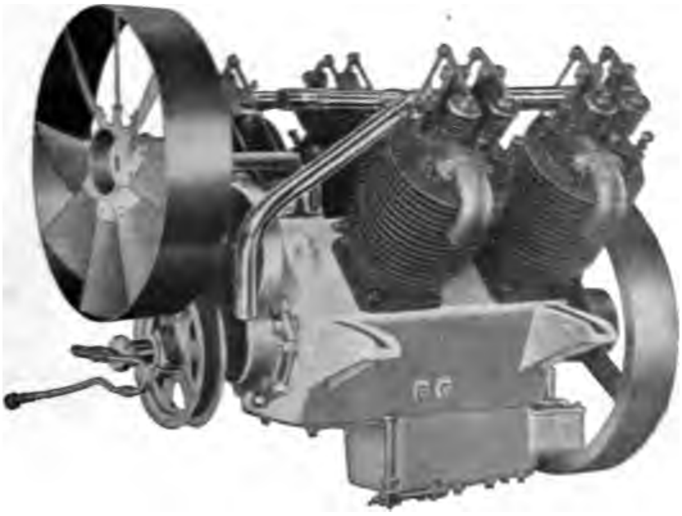

Fig. 71. Marmon Inclined-Cylinder Engine.

vehicles, as in the Marion. But the usual arrangement is lengthwise of the vehicle in vertical position when more than two cylinders are used. In the Marmon the cylinders are inclined two to each side about 30 degrees from a vertical position, while in the Duryea, the cylinders are inclined to the rear, 30 degrees from horizontal. In the Adams-Farwell, either three or five cylinders are used, equally spaced around a vertical axis and arranged to revolve in a horizontal plane. The weight of the cylinders avoids need for a fly wheel and their motion gives an efficient air cooling without fans or other mechanism.

In one or more instances the cylinders have b
equally distant around their axis of revolution and par

which arrangement also secures steady rotation without a fly-wheel, and efficient air cooling. The auto is largely the sport of the wealthy and as is the case with all new things, is frequently provided, to the point of vulgarity, with various fittings and trimmings quite often made to sell rather than to use, and bought rather for ostentation than for any real service. A considerable business is done in these fittings, some of which are quite elaborate and expensive.

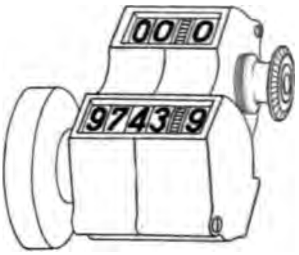
Fig. 72. Odometer.

FITTINGS.

Odometers are arranged with a single dial to give the total distance travelled or with a secondary dial to record the distance of each trip. Speed indicators show at a glance the speed at which the vehicle is traveling at any time, while clocks affixed to the dash board relieve the operator of the necessity of consulting his watch. Gradometers indicate the angle of the hill with more or less accuracy. Manometers tell the story of the water circulation. Voltmeters and ammeters advise concerning the electric circuit and various gauges and glasses show the action of the lubrication, the amount of fuel and water, and the air pressure in the air brake reservoir or gasolene tank as the case may be. Spark coils and acetylene generators, storage tanks and storage batteries are quite frequently in evidence while horns, gongs, or whistles complete the list. Some of the latter are numerous enough and properly toned and arranged to permit playing a tune. All are well in their place but add needlessly to an already

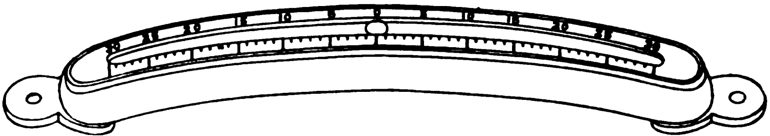
Fig. 73. Gradometer.

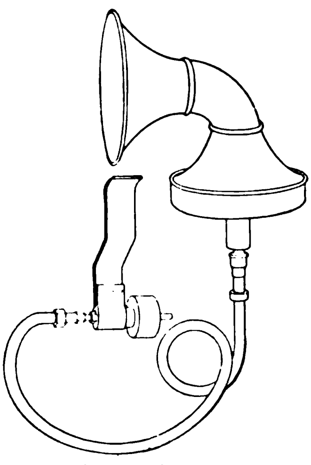
Fig. 74. Siren Horn.

A pulley running on the tire of the vehicle rapidly revolves a disk filled with holes. The result is a loud sound.

complicated vehicle and are not in accord with the simplicity which must accompany an extended use of this valuable invention.

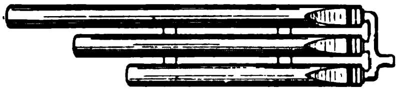

Fig. 75. Three-Toned Horn.

SHOCK ABSORBERS.

The high speeds frequently attained by motor vehicles greatly magnify inequalities of the road surface, with the result that the springs are violently compressed and rebound disagreeably, sometimes breaking. To prevent this, friction surfaces have been applied, which, while they permit yielding, dampen or deaden the spring action and render the vehicle more comfortable. Some forms of these employ pistons with valves or passages which permit free movement in one direction, but not in the other. It is urged against this that at high speed the second inequality is met before the springs have recovered their position, so they are unable to perform their duty.

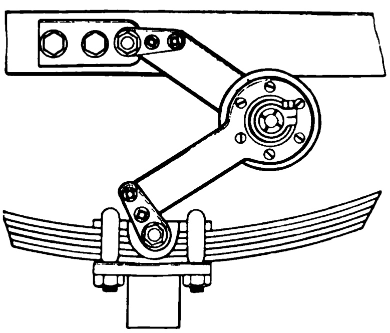

Fig. 76. Shock Absorber.

Springs. The comfort and durability of the vehicle depends largely upon the springs, although following cycle practice, many constructors have depended upon tires for this service. As in carriages, three forms of springs are quite common with a number of less used forms. The full elliptic has always had recognition and is a serviceable spring, but does not offer the rigidity sidewise that the half elliptic secures. It is quite essential that ther ear axle at its sprocket should remain in line with the body or frame which carries the front sprocket, as otherwise the chain may jump off. The full elliptic requires the use of reaches or radius rods to hold the axle in position, but the semi-elliptic is usually fastened to the framework at one end, while the other end is carried by a swinging shackle. Side springs fastened to the body at their centers, and to the axle at their ends, have been much used on cheap constructions, and although not the best form, have given good service.

Spirial springs are sometimes used, principally as an accessory, to modify the action of the main spring or to assist it to carry the load. The high speeds frequently attained by autos, together with the small wheels used, demand exceptionally good spring suspension, which has heretofore been neglected, but is receiving more attention at present. Rubber buffers have been frequently used to prevent overloaded springs, and many a bent or broken axle has been due to improper spring design. In case of a broken spring it is usually possible to fill in the space with a block of wood which will permit the vehicle to be used.

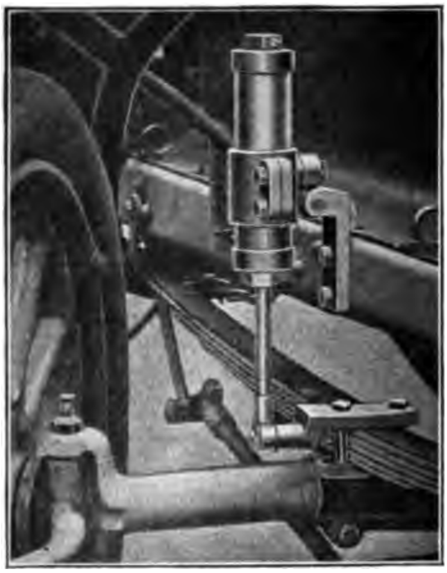

Fig. 77. Air-Cusion Shock Absorber.

Much of the comfort of a vehicle depends upon the upholstering. Deep springs in the cushions and backs add greatly to the ease of riding. This is particularly true in going over gutters or water bars where stiff, firm backs, as found in many tonneaus, transmit to the rider severe jolts, which, if the backs are high, are felt as disagreeable jerks at the neck. For high speed, low backs are more comfortable because they permit the entire spinal column to yield instead of the neck only. Deep springs, however, ease such objectionable features greatly.

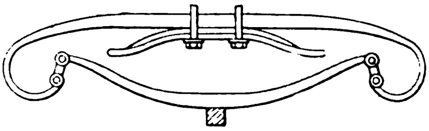

Fig. 78. Semi-Elliptic Rear Spring.

Since the auto is necessarily associated with oil, and is driven at high speeds in all weathers, the upholstering is best of leather or pantasote, so that it may not absorb oil nor dirt nor be soaked and damaged by water.

BEARINGS.

Auto bearings are in general of three kinds, plain, ball and roller. The plain or common carriage bearing gives good satisfaction if frequently oiled and is of low first cost and needs few repairs. Rear axles which revolve are frequently mounted in plain bearings, usually of bronze or babbitt, with equally good results. For light vehicles, particularly with small power, as the light steam and electric carriages, ball bearings are quite common. The small area of the ball races requires that the balls, cups and cones be extremely hard in order to give service, and a broken ball frequently damages the bearing. The operator should listen for grinding or squeaking in the ball bearings and stop and remove the broken ball before further damage is done. For heavier loads, roller bearings are common. These are of several varieties, one well known form employing flexible rollers made by rolling a strip of metal into a spiral. The rollers are usually guided by cages to keep them parallel, and if not so guided should be quite short, preferably of a length not greater than their diameter. Rollers are usually hardened and ground. Conical rollers, also held in cages, are much used and are particularly adapted for places where the strain comes in various directions, as in the hubs of wheels. Ball or roller

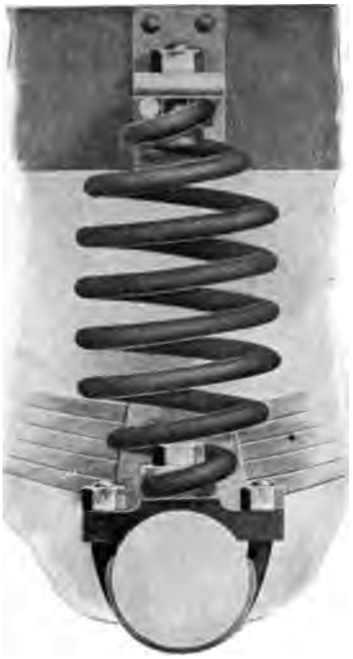

Fig. 79. Spiral Equalizing Spring.

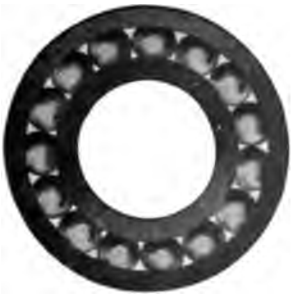

Fig. 80. Ball Bearing.

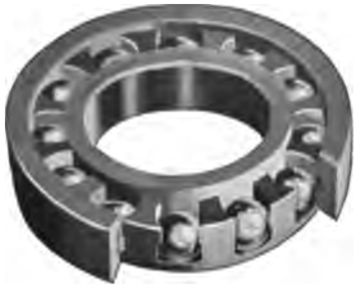

Fig. 81. Annular Ball Bearing.

bearings are much used to receive the thrust of bevel gears or friction disks.

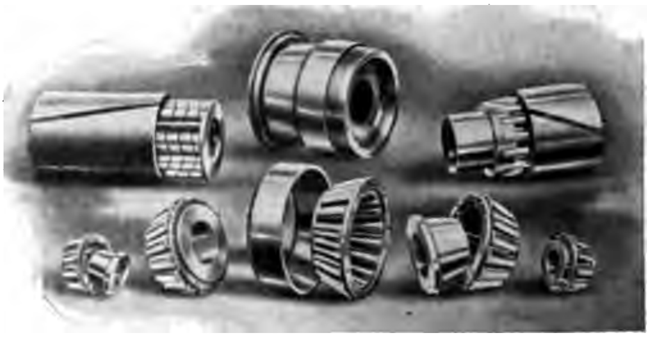

Fig. 82. Plain, Flexible, and Conical Roller Bearings.

LAMPS.

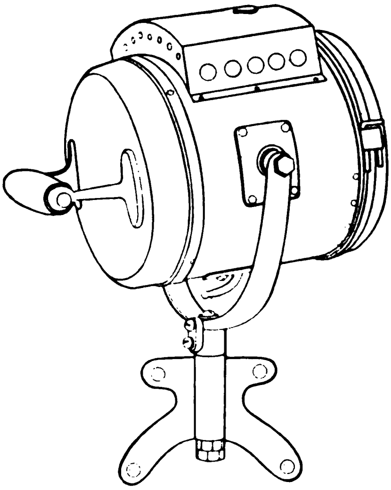

Fig. 83. Automobile Lamp.

The law in most places requires autos to carry lamps, although other vehicles do not as a rule carry them and cannot be seen by the auto driver unless he is provided with a searchlight able to light the road a great distance ahead. Without this assistance he may be unaware that a scary horse is doing damage and therefore unable to stop or govern himself accordingly. The searchlight throws a powerful beam which blinds the horse driver and renders him likely to leave the road. The safest arrangement is for all vehicles to carry a light on dark roads in order that each driver may be aware of the presence of the other.

OPERATION.

The operation of a vehicle depends much upon its particular design and information is usually supplied by the maker. In general, it is necessary to turn on the electric current, the liquid fuel, open the throttle, and turn the starting crank. After the motor starts, adjust the gasolene to give best results, throttle the motor to suit, and set the low clutch gently. This throws a load on the the motor, to overcome which the throttle should be opened correspondingly. As the vehicle starts, feel of the steering to know that the vehicle is under control. As the speed increases change to a higher gear, the object of the skilled driver being to use the high gear as much as possible, in order that the motor may make as few revolutions per mile as may be, thus saving fuel and wear. In no event should the motor be choked down till it is jerky or liable to stop, for this may result in a stop in front of a train or in some similar dangerous and undesirable place.

The brake should be tested at the first opportunity and particularly before starting down a steep hill, so that it may be known to be in perfect order, for next to the ability to go, is the ability to control and stop. If the brake is faulty, the vehicle may be stopped by stopping the motor with the low speed clutch engaged and the clutch may also be used as a brake either instead of the regular brake or in conjunction with it on hills, thus forming a second brake, and one that is usually in order, as proved by the ability to climb hills. The low clutch is very effective and subjects the vehicle to a decided strain on which account it should be applied gently lest a chain be broken or gears stripped. In such an event the vehicle should be turned crosswise the road into the bank if circumstances permit. If the speed is too fast and the road is clear, and straight, the bottom of a hill may be safely reached but this dangerous chance should never be attempted except as a last resort. A properly powered vehicle will climb hills with little loss of time, so there is no need to rush down hill at a dangerous rate or with the vehicle beyond control.

The operator should learn to recognize by ear the proper running of all parts of the vehicle and recognize instantly any deviation therefrom. He should also recognize by the way the vehicle starts or coasts whether it runs freely or not, and by the feel whether a tire is flat or not. Lack of lubrication in the engine or vehicle adds much to the labor and expense and should be sought for and remedied. A weak spark causes a weak engine and signifies that either the batteries need renewal, the generator brushes need cleaning, the driving device is not doing its duty, or the electrical wires and connections are at fault. An excess of lubricating oil will sometimes coat the interior of the cylinder with carbon, which should be removed by scraping, the cylinder heads being taken out for this purpose. The mixture should be right and the proper proportion of gasolene vapor and air must be determined by adjustment and trial. Usually more is required on a dry day than on a wet day because on a wet day the water vapor displaces some of the oxygen, so that less gasolene can be burned. Too much fuel weakens the mixture and soots the plugs and walls.

The cooling devices should be watched that the fan does not stop nor the water tank get empty, although in either case the engine may be run a short distance without damage before it gets hot enough to destroy the lubrication. The gasolene tank and piping should be so simple that it can be easily watched, for a leak is not only wasteful, but dangerous, because of possible fire. The tank should never be exposed to heat or burning vapor and tanks containing pressure are inadvisable because of the more rapid leak in such cases. For cold weather or for starting, a gasolene of low specific gravity, numbered high on the Baumé scale, is best, but a heavier liquid will give more power per gallon. With a hot engine, kerosene can generally be used, a fact which will enable one sometimes to get home after finding the gasolene tank empty. Take great care that the battery is never left on a closed circuit for this quickly destroys its efficiency.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

MARINE BOILERS.

1. Why are center punch marks placed one inch apart on a test piece?

2. Describe the double butt treble riveted joint and state its approximate efficiency.

3. A Purves furnace is 7 feet 6 inches long, 38 inches in diameter and the pressure is 170 pounds per square inch; what should be the thickness of the plate? Ans. .46 inch.

4. What is the difference between ordinary and stay tubes?

5. What constitutes the heating surface of a cylindrical marine boiler?

6. What should be the area of the spring safety valve for a cylindrical boiler having 60 square feet of grate area? English Board of Trade Rules.

7. Why are the ends of some marine boilers curved at the top?

8. Describe briefly the Foster Automatic Stop Valve.

9. Why is a large quantity of salt in the boiler undesirable?

10. Describe the process of building the fire?

11. Why are stud bolts or patch bolts used for repairs instead of rivets?

12. The U. S. S. "Massachusetts" is running with steam up in all the main boilers. If the rate of combustion is 22 pounds of coal per square foot of grate, how many long tons of coal are consumed per day of 24 hours? Ans. 130 tons (about).

13. Give the advantages of corrugated furnaces. Name the most common forms.

14. A test piece from a steel plate shows the following;

area of section before breaking .4375 square inches, load at rupture 24,000 pounds, 4 inches of the central portion stretched to $4\frac{7}{8}$ inches, and the contracted area was .235 inch. Was the plate suitable for boiler construction according to the rule of the U. S. Board of Supervising Inspectors of Steam Vessels?

15. Explain why the furnace doors and smoke box fronts are provided with screen plates.

16. What should be the total area of grate for a boiler that burns 22 pounds of coal per square foot per hour if each pound evaporates 9.5 pounds of water and 15,048 pounds are evaporated per hour? Ans. 72 square feet.

17. Describe briefly the cylindrical marine boiler.

18. Give the requisites of a good boiler covering.

19. How may furnaces that have come down slightly be repaired?

20. What are the requisites of a marine water-tube boiler?

21. Describe, with sketch, the test piece for iron plate prescribed by the U. S. Board of Supervising Inspectors of Steam Vessels.

22. If a piece of plate having a reduced section of .38 square inch breaks at a load of 22,000 pounds, what is the tensile strength? Ans. 58,000 pounds (nearly).

23. Describe the hydrometer. How is it graduated for a salinometer-pot?

24. Give the advantages and disadvantages of mechanical draft. Describe briefly the methods of application for marine work.

25. Why should not the main stop valve be closed tightly while steam is forming?

26. The distance between the extreme center punch marks is 8 inches before and 10 inches after testing. What is the per cent. of elongation?

27. A steel bar $\frac{3}{4}$ inch in diameter and 8 inches long in the central portion gave the results shown in Fig. 12. What was the actual elastic limit, breaking strength of actual section and to what length did the 8 inches stretch?

$$\text{Ans.}\begin{cases}\text{17,700 lbs. (about)}\\ \text{43,700 lbs. (about)}\\ \text{8.864 inches.}\end{cases}$$

28. A double ended Scotch boiler is 15 feet in diameter; the efficiency of the joint is .84. If the working pressure is 160 pounds and the plate has a tensile strength of 60,000 pounds what should be the thickness of the plate if the factor of safety is 4.5? Ans. $1\frac{1}{4}$ inches.

English Board of Trade Rules.

39. What would be the working pressure in the above boiler having plates $1\frac{1}{4}$ inches thick if the Rules of the U. S. Board of Supervising Inspectors of Steam Vessels are followed?

Ans. 167 pounds.

30. State the properties of steel for boiler construction. Why is steel of a high tensile strength not suitable?

31. According to the Rules of the U. S. Board of Supervising Inspectors of Steam Vessels, what should be the allowable working pressure in a boiler if the short screw stay bolts are spaced 8 inches apart and the plate is $\frac{9}{16}$ inch thick?

32. State several reasons why water-tube boilers are better than cylindrical boilers for marine work.

33. Explain the reasons why the level in the gage glass may not be the same as the water level in the boiler.

34. Explain the difference between a hard patch and a soft patch.

35. What should be the diameter of the two safety valves of a boiler having 4310 square feet of heating surface and working at 160 pounds pressure? Ans. $4\frac{3}{8}$ inches.

Use French Government Rule.

36. Describe briefly the causes for loss in efficiency in the furnace of a marine boiler.

37. Where should the feed water be introduced into a cylindrical marine boiler?

38. What is the area in square feet through a nest of 84 wrought lap welded boiler tubes having an external diameter of $2\frac{1}{4}$ inches? Ans. 1.933 sq. ft.

REVIEW QUESTIONS

ON THE SUBJECT OF

MARINE ENGINES.

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1. How could a vertical marine engine be run if the go-ahead eccentric breaks?

2. Sketch the arrangement of the cylinders of a three-cylinder compound engine and show where the steam enters and leaves the cylinders.

3. Referring to Fig. 41, how many tons of coal must be burned per day to attain a speed of 16 knots?

4. Define the pitch of a screw propeller.

5. Explain with sketch a method of marking off nuts.

6. Why are leads taken?

7. Give the advantages of a centrifugal pump.

8. A ship is steaming at a speed of 13 knots per hour. The screw has a pitch of 17½ feet. What is the apparent slip in per cent. if the engines are working 84 revolutions per minute?

9. Sketch some method for securing the liner of a cylinder in place, showing how it is made steam tight at both ends.

10. What is the displacement in tons if the volume of the ship under the water line is 26,250 cubic feet?

11. Describe the cylinder relief valve. Where are they placed?

12. If a propeller shaft is 14 inches in diameter and there are 7 collars what should be the diameter of the collars if the total thrust is 48,000 pounds? Ans. 18½ inches.

13. How is a thrust block constructed so that the collars may be separately adjusted?

14. Explain with sketch how condenser tubes are placed in the tube plates.

15. If a vessel is steaming at the rate of 1720 feet per minute, how many knots will it travel in 3 hours?

16. In the above ship, how many turns must the engine make if the pitch is 21 feet and the apparent slip 18 per cent?

17. If the pointer of the vacuum gage stands at 25 what is the absolute pressure in the condenser?

18. What is the effect on the temperature of the feed water if the vacuum is made more nearly perfect?

19. Explain the keel condenser.

20. How is a piston made steam tight?

21. Why should the caps of bearings and connecting-rod ends be screwed hard to the liners?

22. Explain the centrifugal lubricator.

23. How is the expansion varied independently in the cylinders of a triple expansion engine?

24. Why should water from the stokehold bilges be carefully strained before going to the boilers?

25. What construction is used to make all the links of a multi-cylinder engine move at once?

26. What should be done in case the high pressure valve breaks and cannot be repaired and the air-pump is worked from the high pressure crosshead?

27. Of what use are by-pass valves?

28. What causes "gagging"?

29. In finding the pitch of a propeller, a point on one of the blades moved 2 inches while it passed through an angle of 8 degrees. What was the pitch? Ans. $7\frac{1}{2}$ feet.

30. A screw propeller is 14 feet in diameter and the pitch ratio is 1.2. What is the pitch?

31. What causes hot bearings?

32. Why should not water be applied to a hot piston-rod?

33. Name a few causes that prevent the starting of a marine engine?

34. Trace the course of the circulating water from its entrance to the ship to its exit; naming the valves, pipes, pumps, etc., through which it passes.

REVIEW QUESTIONS

ON THE SUBJECT OF

NAVIGATION.

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1. What are parallels of latitude, meridians, small circles, great circles?

2. Define the terms longitude and latitude.

3. What is difference of longitude, difference of latitude?

4. Explain the term "Departure" and its relation to longitude.

5. Describe "The course steered."

6. Describe the compass and "box" it. (This must be done without reference to the text.)

7. Tell in your own words what you can about magnetism, dip, variation, and deviation.

8. Correct the following courses:

	(1)	(2)
Compass course . .	. E.N.E.	S.W.S.
Variation	. 12°– 0′ E.	20° 0′ E.
Deviation	. 19°–30′ E.	11° 45 W.

Find true course.

Given true course	N. 3° E.
Deviation	3° 45′ E.
Variation	12°– 0′ W.

Find compass course.

9. Give a short description of a Mercator's chart, stating its characteristics and advantages for ocean work.

10. What is the latitude and longitude of the points *A*, *B*, *C*, *D*, *E*, and *F* in Fig. 7?

11. What is the distance in nautical miles from *C* to *D*; from *A* to *B*; *D* to *E*.

12. Give a brief account of the different kinds of "sailings."

13. What can you say regarding the following; Taking the Departure, Day's Work, Making the Land, and Sounding.

14. What is Dead Reckoning?

15. Explain the following: Altitude and Declination of a Celestial Body, Zenith and Polar Distance, Hour Angle.

16. Explain thoroughly the corrections which must be applied to a sextant reading to get the true altitude of a heavenly body.

17. Given the following observed altitude of the sun, work out the latitude, using to obtain any necessary data the tables on pages 50 and 51: At sea, May 6, 1902, longitude 67° 45′ W., observed alt. sun's lower limb, 68° 50′, index correction + 2′, dip 4′ 23″, parallax 3″. Find latitude.

18. What is solar time, a chronometer, apparent time, siderial time?

19. Explain the difference between civil and astronomical time.

20. Explain the longitude problem in detail, giving every step. After you get the apparent time at ship, how is the longitude obtained from it?

21. Explain finding the longitude by the method of equal altitudes.

22. Describe briefly the advantages of Sumner's method.

23. Tell what you can about finding compass deviations by azimuths of the sun.

24. What effect does heeling error have on a ship?

25. Correct the following courses:

True course	W. N. W.
Variation	15° W.
Deviation	8° E.
Ship on starboard tack	½ pt. leeway.

Find compass course.

25.

Compass course	E. by S.
Variation	11½° W.
Deviation	½ pt. W.
Ship on port tack	¼ pt. leeway.

Find course made good.

REVIEW QUESTIONS

ON THE SUBJECT OF

LOCOMOTIVE BOILERS AND ENGINES.

PART I.

1. **What is the fibre stress on a side rod like that shown in Fig. 43, when running on an engine having driving wheels 62 inches in diameter and a piston stroke of 24 inches at a speed of 50 miles an hour? The weight of the ends may be neglected.**

Ans. 7,800 pounds.

NOTE: Assume the weight of the rod to be 152 lbs. then calculate the centrifugal force and finally the stress, considering the centrifugal force as the load.

2. By what means can the use of stay bolts in locomotive boilers be avoided?

3. At what point in the boiler does the greatest amount of stay bolt breakage occur?

4. With one square inch of valve area to three square feet of grate area, what size safety valves would be used on a boiler having a firebox 116 inches long and 89 inches wide?

Ans. Three valves of 3½ inches diameter.

5. What stroke of piston should be given to a locomotive in which the cylinder diameter is 17 inches; the weight on the drivers 85,000 pounds, the diameter of the drivers 56 inches, and the boiler pressure 180 pounds per square inch?

Ans. 25.4 inches. Use 24 inches.

6. What should be the diameter of the cylinders of a locomotive in which the weight on the driving wheels is 118,000 pounds, the diameter of the driving wheels 62 inches; the boiler pressure 180 pounds per square inch, and the piston stroke 30 inches?

Ans. 19⅜ +. Use 19½ inches.

7. What is the object of making tubesheets thicker than the side sheets of a fire-box?

8. What advantage does a small cylinder with a long stroke possess over a large cylinder with a short stroke, the horse-power developed being the same?

9. What pressure per square inch of surface will be required to give a permanent set to a steel firebox sheet? The thickness is $\frac{3}{8}$ inch; the staybolts are spaced 5 inches from centre to centre and the heads are $1\frac{3}{8}$ inches in diameter.
Ans. 513.69 pounds.

10. What stress per square inch of section will be put upon the staybolts of a fire-box working under a pressure of 175 lbs. per square inch, the stay-bolts to be 1 inch in diameter and spaced $4\frac{1}{2}$ inches from centre to centre? Ans. 4337 lbs.

11. How does the exhaust jet produce a draft through the tubes of a boiler?

12. What weight can be put upon the driving wheels of a locomotive, in which the diameter of the driving wheels is 62 inches; the boiler pressure 200 pounds per square inch; the piston stroke 30 inches and the diameter of the cylinder 21 inches? Ans. 153,755 pounds.

13. What boiler pressure can be used upon a locomotive having cylinders 18 inches in diameter with a piston stroke of 24 inches and a weight of 88,000 pounds upon the drivers, that are 64 inches in diameter? Ans. 201 pounds.

14. Why are brick arches to be preferred to water tables in the fire-box?

15. To what pressure is the dry pipe subjected?

16. What is the object of balancing a throttle valve?

17. What should be the length of a test piece of stay-bolt iron at the moment of fracture? Ans. 10.4 inches.

18. On what does the tone of the whistle depend?

19. How does the blower act to cause a draft through the fire-box?

20. What is a tell-tale hole?

21. What must be the length of a piece of fire-box steel at the moment of fracture? Ans. 10.24 inches.

22. What is the effect of an increase in the amount of coal burned upon a grate?

23. What are the three positions in which the mud-ring is placed and which govern the width of the fire-box?

24. What are the losses that combine to make up the fall in efficiency due to an increase of coal burned?

25. What size of driving wheels should be used on a locomotive in which the boiler pressure is 180 pounds per square inch; the piston stroke is 24 inches, the diameter of the cylinder is 17 inches and the weight on the driving wheels is 90,000 pounds. Ans. 50 inches.

26. According to Hutton's formula (Construction of Boilers, page 52) what should be the thickness of a wrought-iron dry pipe of a locomotive boiler, having a diameter of 6 inches, and a factor of safety of 6, the steam pressure to be 150 pounds per square inch and the length of the pipe 8 feet?

Ans. 9.39 thirty-seconds.

27. What three methods are in use for supporting the crown sheet?

28. What is the thrust upon the parallel rod of a locomotive having cylinders 18 inches in diameter and carrying a steam pressure of 180 pounds per square in.? Ans. 22,902 pounds.

29. What would be the pressure per square inch of section, under the conditions of example 28, on a rod like that shown in Fig. 43? Ans. 3,962 pounds.

REVIEW QUESTIONS

ON THE SUBJECT OF

LOCOMOTIVE BOILERS AND ENGINES.

PART II.

1. What is negative inside lap and where is it used?

2. What are the essential characteristics of a logging locomotive?

3. What is the tractive power of a locomotive having cylinders 21 inches in diameter with a piston stroke of 26 inches, driving wheels 54 inches in diameter and working under a mean effective pressure of 170 pounds per square inch?

Ans. 36,096.6 pounds.

4. How many and what are the types of the compound locomotives?

5. What will be the total resistance of a train consisting of a locomotive weighing 150,000 pounds and cars weighing 280,000 pounds, when running at a speed of 40 miles an hour up a .7 per cent. grade and on a curve of 4½ degrees?

Ans. 6513. pounds.

6. In what position should the reverse lever be in on starting a train?

7. Of what value is a balanced valve?

8. Suppose a train, weighing with the locomotive 300 tons, is to be run for a distance of 55 miles at an average speed of 60 miles per hour.

a. What is the train resistance per ton?

b. Assuming 75% efficiency, what should the I. H. P. be?

c. If the locomotive uses 35 pounds of water per I. H. P. hour what should be the capacity of the tank in gallons, allowing 25% for reserve?

d. How many tons of coal will this require, allowing 7 pounds of water per pound of coal?

9. What is the object of counterbalancing a locomotive?

10. What is the resistance due to grade only, of a freight train weighing 2,000,000 pounds, moving up a grade of .9 of one per cent?

Ans. 18,000 pounds.

11. What is the difference between a home and an advance signal?

12. Where should the reverse lever be placed when running with the throttle closed? State reason for answer.

13. What are rack locomotives and where are they used?

14. What will be the resistance on a straight track, of a train of cars weighing 240,000 pounds running at a speed of 50 miles per hour?

Ans. 1,740 pounds.

15. When a distant signal is set in the danger position, what does it signify?

16. A consolidation locomotive weighing 137,950 pounds has 117,400 pounds on the driving wheels. The weight of the reciprocating parts on one side of the engine is 680 pounds. The stroke of the piston is 26 inches. The diameter of the driving wheel is 56 inches.

a. What weight of reciprocating parts must be balanced?

b. What weight must be added to each driving wheel if the center of gravity of the counterbalance thus added is to be 19 inches from the center of the wheel?

c. At a speed of 25 miles per hour, what increase, over the static load, will the counterbalance given in *b*, put upon the track due to its centrifugal force?

Ans. { *a.* 335. pounds.
b. 57. pounds.
c. 696. pounds.

17. What should be the length of the radius bar of a mogul locomotive, having all drivers flanged, a rigid wheel base 15 feet 2 inches long, and a distance of 8 feet from the front driver to the truck center?

Ans. 5 feet 11.2 inches.

18. The high pressure cylinder of two-cylinder compound locomotive is 20 inches in diameter. What should be the diam-

eter of the low-pressure cylinder according to the prevailing practice in the United States?

Ans. 29 inches.

19. What should be the length of radius bar in a locomotive having all drivers flanged, a rigid wheel base 12 feet 8 inches long, and 7 feet 5 inches from the front driver to the truck center?

Ans. 5 feet 5 inches.

20. What is the resistance due to curvature only of a passenger train consisting of a locomotive weighing 120,000 pounds and cars weighing 200,000 pounds, moving around a 4-degree curve?

Ans. 616 pounds.

21. What do the following signal colors mean? Red, Blue, Green and White.

22. What is the advantage of the compound locomotive? Under what conditions does this type show the greatest economy?

23. What is the use of a relief valve on a steam chest?

24. A mogul locomotive weighing 120,000 pounds has 107,000 pounds on the driving wheels. The weight of the reciprocating parts on one side of the engine, including the front end of the connecting-rod, is 620 pounds. The stroke of the piston is 24 inches. The diameter of the driving wheels is 56 inches.

a. What weight of reciprocating parts should be counterbalanced?

b. What weight must be added to each driving wheel if the center of gravity of the counterbalance thus added is 18 inches from the center of the wheel?

c. At a speed of 45 miles an hour, what increase, over the static load, will the counterbalance in *b*, put upon the track due to its centrifugal force?

d. What is the maximum weight of the reciprocating parts of this engine that can be counterbalanced with safety?

Ans. *a.* 320 pounds.
b. 71. pounds
c. 2653. (about) pounds.
d. 334 pounds.

25. What is the tractive power of a locomotive having a cylinder 18 inches in diameter with a piston stroke of 24 inches

and driving wheels 62 inches in diameter, and working under a mean effective steam pressure of 140 pounds per square inch?

Ans. 17,558 pounds.

26. What is the resistance due to acceleration only of a train weighing 200 tons that is accelerated from a speed of 50 to 60 miles an hour in a distance of one mile?

Ans. 264 pounds.

27. Name the parts comprising the link motion.

28. Why is the counterbalance placed near the tire rather than near the center of the driving wheel?

29. Describe the ten-wheeled type of locomotive.

30. Why is it not necessary to use a receiver with the Baldwin four-cylinder compound locomotive? What is the disadvantage of this type?

REVIEW QUESTIONS

ON THE SUBJECT OF

THE AIR BRAKE.

1. How does the compressed air apply the brakes?

2. What was the first and simplest form of air brake?

3. Is the use of straight air brakes now allowable?

4. What necessary parts has the automatic brake on a car which the straight air brake had not?

5. Where is the compressed air kept ready for use in the automatic air brake?

6. Where does the compressed air come from directly, that enters the brake cylinder when the automatic brake is applied?

7. How is the automatic brake applied and released?

8. How is the train pipe coupled up between the cars?

9. Why is it necessary to close the train pipe on both sides of the hose coupling before it is parted?

10. Why must the brakes be fully released before uncoupling the hose between the cars?

11. In coupling or uncoupling the hose between cars, what must be done if there is ice upon the couplings?

12. What pressure should be carried in the train pipe and auxiliary reservoir?

13. How much air pressure should be carried in the air signal train pipe?

14. When taking up the slack of the brake shoes how far should the brake piston travel in the cylinders on cars and tenders with a full application of the brake?

15. What is the pressure-retaining valve and what is its use?

16. How should the air pump be started?

17. How should the steam cylinder of the air pump be oiled, and what kind of oil should be used?

18. How should the air cylinder of the air pump be oiled, what kind of oil, and why?

19. What regulates the train-pipe pressure?

20. When the engine is coupled to the train, why is it necessary to have the full train-pipe pressure and the excess pressure in the main reservoir?

21. Why should the driver brakes always be operated automatically with the train brake?

22. In making a service application of the brakes, how much reduction of the train-pipe pressure from 70 pounds does it require to get the brake full on?

23. What should the first reduction be in such an application and why?

24. What is the result of making a greater reduction of pressure than 20 pounds?

25. How many applications of the brakes are necessary in making a stop?

26. In releasing and recharging the train, how long should the handle of the engineer's valve be left in the release position?

27. In making service stops with passenger trains why should you release the brakes a little before coming to a full stop?

28. When the brakes go on suddenly when not operated by the engineer's valve, and the gauge pointer falls back, what is the cause, and what should you do?

29. Are the brakes liable to stick on after an emergency application, and why?

30. In descending a grade how can you best keep the train under control?

31. If the train is being drawn by two or more engines, upon which engine should the brakes be controlled, and what must the enginemen of the other engines do?

32. What is the result if water is allowed to collect in the main reservoir of the brake apparatus?

33. If the hose bursts upon the run, what must be done?

34. If the train breaks in two what must be done?

35. Explain how the pressure-retaining valves are thrown into action or thrown out of action, and when this must be done.

36. If the brake of any car is found to be defective on the run, how should you proceed to cut it out?

37. What is the conductor's valve, and what is its use?

38. What is the car signal for, and how is it operated?

39. How is the slack taken up so as to secure the proper adjustment of piston travel?

40. Why is it important that no leaks should exist in the air brake service?

41. To what travel of piston must the brakes be adjusted?

42. How is the slack taken up so as to secure this adjustment?

43. How many forms of triple valves are there in use, and what are they called?

44. How can you tell the plain triple from the quick-acting triple?

45. What is an air brake?

46. How is the air compressed?

47. How does the piston rod get back when the brakes are released?

48. How was the straight air brake applied and released?

49. How does the compressed air get into the auxiliary reservoir?